J. B. Mawdsley

PROVINCE OF MANITOBA

DEPARTMENT OF MINES AND NATURAL RESOURCES

MINES BRANCH

PUBLICATION 54-2

JURASSIC STRATIGRAPHY OF MANITOBA

By

DONALD F. STOTT

WINNIPEG

1955

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ABSTRACT

Rocks of the Jurassic system extend northeastward over the shelf area of the Williston Basin and are found in 27,000 square miles of southwestern Manitoba where they unconformably overlie Paleozoic rocks and underlie Cretaceous sediments. It is divided into four formations, which are from the base upward; Amaranth, Reston, Melita, and Waskada.

Lower Jurassic rocks are absent in Manitoba. In the Middle Jurassic, an assemblage of gypsiferous red beds, anhydrite, and dolomite are included in the Amaranth formation. The remainder of the Middle Jurassic shales, argillaceous and oolitic limestones is placed in the Reston formation. The Upper Jurassic strata consist of the Melita formation which contains varicoloured shales and thin bands of limestone, and the Waskada formation which contains sand and shale beds.

Depositional conditions and correlation problems related to the basal red beds, to the division between Middle and Upper Jurassic sediments, and to the upper limit of the Jurassic system are discussed.

THE JURASSIC STRATIGRAPHY OF MANITOBA

CHAPTER I

INTRODUCTION

Rocks of Jurassic age occur in the southwestern part of Manitoba, representing deposits on the fringe of the Williston basin area of north-central United States. They are a continuation of beds occurring to the southwest in Wyoming, Montana, North and South Dakota, and to the west in the southern parts of Saskatchewan and Alberta. Jurassic outcrop areas are only found in the Rocky Mountains and the Black Hills of South Dakota. Jurassic bedrock occurs beneath a thick cover of glacial drift along a narrow belt in central Manitoba, but it is covered by Cretaceous sediments throughout the remainder of the Plains area.

A study of the Jurassic stratigraphy of Manitoba has been hindered by the lack of outcrop and subsurface information until an increased drilling program in recent years furnished sufficient data to correlate the lithologic units and outline the history of the Jurassic system in the area.

PURPOSE AND SCOPE OF THE STUDY

Although strata of Jurassic age have been recognized in Manitoba since 1933, their distribution and lithology in this area have not been well known. Interest in the Jurassic stratigraphy of Manitoba has greatly increased within the last two years because of the discovery of oil in Jurassic beds at Wapella, about twenty-five miles west of the Manitoba-Saskatchewan border.

An attempt is made in this paper to describe the stratigraphy of the Jurassic system in Manitoba, and to indicate the relationships of this section with similar deposits in northern United States and Canada.

The present study, made during the winter of 1953-1954 at the University of Manitoba, covers an area which includes

The southwestern corner of Manitoba, the southeastern part of Saskatchewan and the northern area of North Dakota. The extent of the Jurassic sediments in the Great Plains area, the Jurassic "outcrop" area in Manitoba, and the area of the present study are shown in Figure 1.

The lithologic description was obtained from a study of cuttings from oil wells. Samples from fifty wells were examined, and lithologic descriptions of twenty-four sub-surface sections were available to the writer. The tops determined by the North Dakota Geological Survey were used for twelve wells. These are believed to be equivalent to those determined by the writer. When available, electric and/or radioactive logs were used in conjunction with this study. In the Jurassic section of Manitoba, core has been taken from only a few intervals and all of it was examined.

Each well has been given a reference number and these control points are shown on the index map (Plate 3). The data pertaining to these wells are given in Appendix I. Lithologic descriptions of wells shown on the cross-sections are included in Appendix II.

PREVIOUS WORK

The literature describing rocks of Jurassic age in Manitoba is limited. This may be explained by the complete lack of exposures, and by the scarcity of subsurface information before 1950.

Although Tyrrell[1] did not recognize the Jurassic section, samples from three wells in Manitoba which probably penetrated it were described by him in 1892. The descriptions are too generalized to determine any units that might correspond with those outlined in this paper.

Dowling (1919) indicated that a total of 230 feet of samples from a well at Neepawa could possibly be Jurassic shales but no detailed description of the rocks was made at that time.

Wallace (1925) suggested that during late Paleozoic, Triassic and Jurassic times, the Manitoba area was entirely above the sea. Kirk (1929) reported that no evidence was present to prove or disprove the presence of Jurassic rocks; he believed that, in northern Manitoba at least, the basal Cretaceous beds rested upon Devonian rocks.

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[1] Complete references to discussions by persons indicated in this paper may be found in the bibliography.

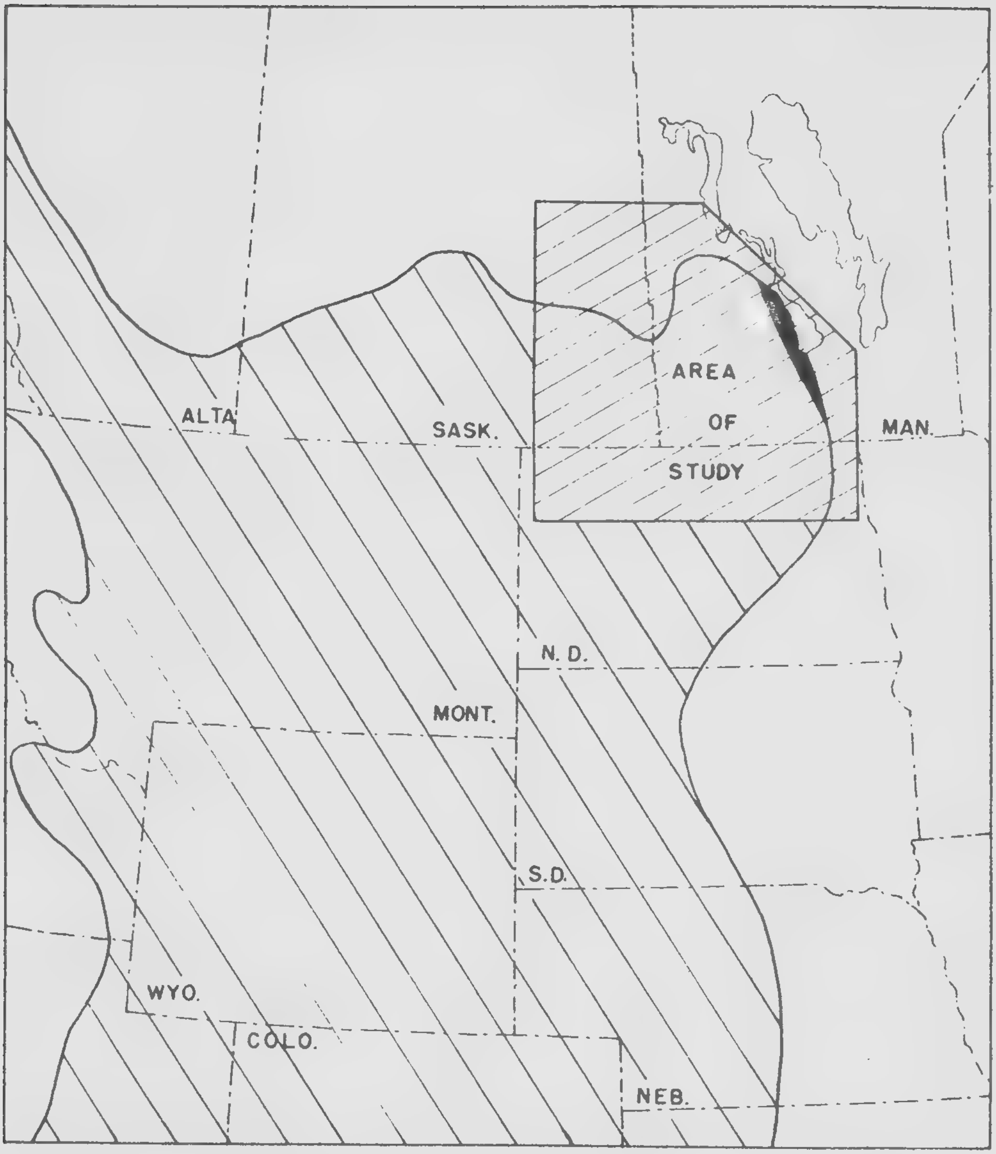

FIGURE I. DISTRIBUTION OF JURASSIC SEDIMENTS IN THE WESTERN INTERIOR REGION (after IMLAY, 1949).

JURASSIC ROCKS UNDER COVER OF GLACIAL DRIFT

AREA CONTAINING JURASSIC ROCKS

Rocks of Jurassic age were not definitely recognized until 1933 when Wickenden suggested, on the basis of paleontological evidence obtained from the Manitou and Dauphin wells, that three Jurassic members or possibly formations were present. Some of the foraminifera from these wells and from beds of similar lithology and stratigraphic position in Alberta and Saskatchewan were described by him in a paper in 1944, which indicated that these rocks were of late Middle or early Upper Jurassic age. In 1945, Wickenden defined the Amaranth formation as those rocks lying between known Jurassic and Devonian rocks.

Jurassic and Amaranth rocks were also described by Kerr in 1949.

In a paleoecologic study of the Jurassic system in the United States, Imlay (1949) indicated on his maps the occurrence of Jurassic rocks in Manitoba and discussed the environmental conditions in which they were deposited.

Schmitt (1955) extended the nomenclature of the Jurassic formations of Wyoming and the Black Hills into Manitoba, using Moore #1 and Langford #1 wells for his correlations.

ACKNOWLEDGMENTS

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This report was prepared under the supervision of Professor E. I. Leith of The University of Manitoba. His guidance, advice, and constructive criticism are gratefully acknowledged. To the other professors of the Geology Department, many thanks are offered for their help.

The writer is indebted to Mr. J. R. Ower who first suggested that the Jurassic stratigraphy would provide a variety of problems for a Master's thesis. Particular thanks are extended to him and to Mr. M. Stanton, both of the California Standard Company, for their encouragement, advice, and assistance in the preparation of this report.

Dr. Wilson M. Laird, State Geologist, North Dakota, kindly supplied lithologic descriptions of several wells which enabled correlations to be made from Manitoba.

Thanks are extended to Mr. L. Vigrass whose suggestions and thesis on the Jurassic stratigraphy of Saskatchewan were helpful in correlation.

CHAPTER II

GENERAL STATEMENT OF STRATIGRAPHY

AREAL EXTENT

Jurassic beds are found in subsurface sections of North Dakota, the southern part of Saskatchewan, and in the southwest corner of Manitoba. In Manitoba, they form a wedge-shaped deposit which is thickest to the southwest and thins to a feather edge south of the town of Swan River, along Lake Dauphin, and Lake Manitoba. This wedge has been produced by pre-Cretaceous erosion which has truncated the deposits, leaving beds of younger age toward the southwest.

A narrow belt of Jurassic rock near Lake Manitoba lies directly beneath glacial drift.

SUBDIVISION AND NOMENCLATURE

A conference of geologists in February, 1953, attempted to establish a standard Jurassic nomenclature for the Williston basin area, but it has not been formally adopted.

Jurassic terminology has developed in three areas. Imlay (1947) described the section in the Black Hills and Wyoming area. Cobban (1945) and Weir (1949) discussed the formations in Montana and Alberta. Schmitt (1953), and Hadley and Milner (1953) described the units in the Williston basin area of North Dakota and Saskatchewan. Correlations are shown in Table 1.

A new nomenclature for the Jurassic section was introduced by the Williston Basin Correlation Committee in February, 1953 (Francis, 1954). The names of Saskatchewan towns were applied to units of a previous classification known as the J Classification. The basal anhydrite and red bed sequence was called the Davidson formation, a name previously used by Bailey (1953) for a formation of Devonian age. The name of the Jurassic Davidson formation has now been changed to Watrous. A sequence of sandstones, shales, and limestones, lying above the basal unit and equivalent to the J-3 and J-4A units of the older classification is called the Gravelbourg formation. Another sequence with well developed electric log characteristics is called the Shaunavon formation. It is equivalent to the J-2A and J-2B units of the

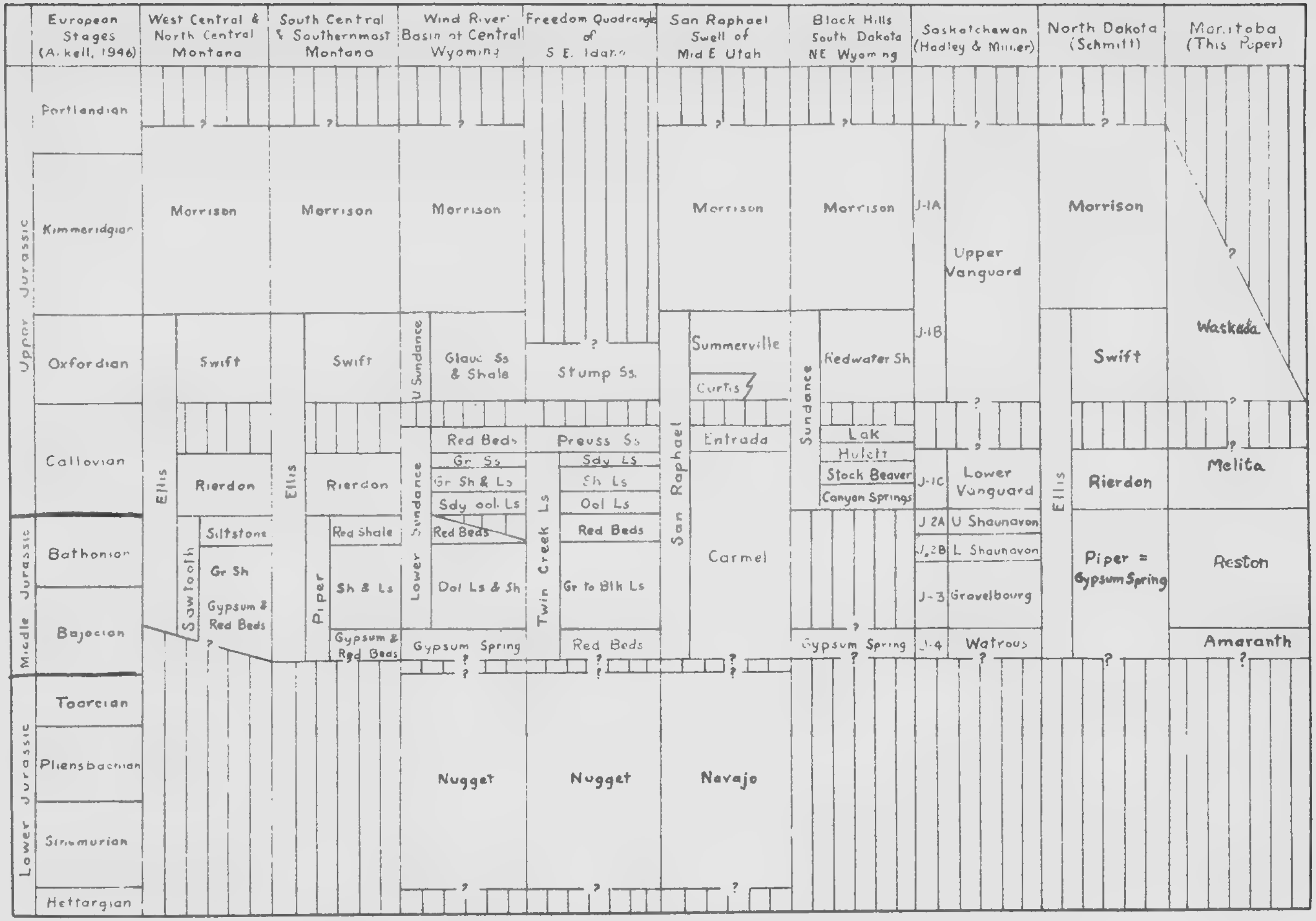

Table 1. Correlation of the Jurassic Formations in the Western Interior Region
(First 7 Columns from Imlay, 1949)

see also Table 2, page 36.

J classification. The top of the Lower Shaunavon formation is usually taken as equivalent to the top of the Piper limestone. The uppermost Jurassic beds, equivalent to J-1A, J-1B, and J-1C have been included in the Vanguard formation.

Wickenden (1945) extended the use of the name Amaranth, as suggested by Kirk (1929) on his manuscript map for gypsum-bearing beds in the vicinity of Amaranth, to beds of similar lithology and stratigraphic position found in subsurface sections of Manitoba.

The use of Saskatchewan terminology has not proven feasible for the divisions in Manitoba. In the area near the eastern limit of Jurassic deposition, interfingering and thinning of beds result in the loss of distinguishing characteristics of these units.

OUTLINE OF STRATIGRAPHIC UNITS

Jurassic strata of the area consist of an assemblage of red beds, evaporites, argillaceous and fragmental limestones, and shales. The limestones, evaporites, and red beds show remarkable lithologic continuity throughout the area, although some variations in thicknesses occur. Many lithologic and thickness variations occur both vertically and laterally in the shale section.

The Jurassic system is divided into four major units of formational rank, to which local geographic names have been applied. These formations do not necessarily correspond to time units because the upper and lower units have been defined on lithologic changes. These divisions have been found to have cartographic limits.

Although the anhydrite and red bed sequence in Manitoba and Saskatchewan are equivalent, some discord exists over the name. As correlation has been made with the "outcrop" of the Amaranth formation and as it has priority over names applied to the beds elsewhere, the name Amaranth is used in the present discussion for the basal Jurassic beds. This formation has been divided into two units because of the change in lithology. The Lower Amaranth unit contains the basal Jurassic beds, and consists of red shales, siltstone, and sandstone. The Upper Amaranth unit is composed predominantly of anhydrite and dolomite, and is sharply defined by electric log characteristics. Gypsum is being mined at Amaranth, west of Lake Manitoba.

Above the Amaranth formation, a shale and limestone unit has been named Reston, after the village in the area of typical development. The Reston formation is characterized by

argillaceous limestones with a band of calcarenite at the top of the section.

The upper portion of the Manitoba Jurassic section has been divided into the Melita formation and Waskada formation.

In Manitoba, the Melita formation, named after the town of Melita, has been divided into the Lower and Upper Melita units. The Lower Melita unit consists of varicoloured shales, sandstones, and limestones. The Upper Melita unit is predominantly green to greyish-green shales with some limestone bands.

The Waskada formation, which derives its name from the village of Waskada, includes all the beds from the top of the Melita formation to the base of the Lower Cretaceous sands. These beds include fine calcareous sands, green and grey shales. Within Manitoba, this formation is present only in the extreme southwestern corner and may include beds which are known as the Morrison formation in North Dakota.

A brief summary of the lithology and maximum thickness for each Jurassic unit is given in the Table of Formations.

TABLE OF FORMATIONS

	Formation	Member	Lithology	Maximum Thickness
Upper Jurassic	Waskada		Grey to green shales with fine-grained, Calcareous sandstone.	+175
	Melita	Upper Melita	Greenish-grey to grey shales and argillaceous limestone.	+275
		Lower Melita	Varicoloured shales with some argillaceous limestone and sandstone	+200
Middle Jurassic	Reston		Upper part marked by calcarenite; argillaceous limestone and shales toward the base.	+150
	Amaranth	Upper Amaranth	Predominantly white anhydrite with interbeds of buff dolomite and brown to grey shales.	+150
		Lower Amaranth	Brick red, silty shale with some gypsum and anhydrite; breccia at base.	+125

CHAPTER III

DESCRIPTIVE STRATIGRAPHY

In this chapter, the four formations of Jurassic age are described in detail from a study of samples and core recovered from wells in the area. An isopach map of the Jurassic system is included (Plate 8).

UNDERLYING STRATA

Jurassic sediments lie unconformably on rocks of Paleozoic and possibly Triassic age. South of Portage la Prairie, Silurian rocks underlie the sediments. Jurassic strata rest upon Devonian rocks within the remainder of the subject area in Manitoba with the exception of 4,000 square miles in the southwest corner, where they overlie Mississippian rocks. Mississippian beds occur beneath the Jurassic rocks throughout most of Saskatchewan and North Dakota. The distribution of the rocks of the underlying system is shown in Figure 2.

A structure contour map has been drawn on the top of the Paleozoic sediments (Plate 9).

The most remarkable feature related to the underlying strata is found near Hartney. A difference of 800 feet in elevation exists between the base of the Jurassic sediments in the California Standard Hartney #16-33 (5-24W1) and Royalite East Hartney #1 (7, 27-5-24W1) wells (no structure contours have been placed on the map around the California Standard well). Mississippian and some Devonian beds which occur in the Royalite well are not present in the California Standard well.

In some areas, the Reston limestone rests upon Paleozoic limestone, and this could cause some errors in the determination of the contact. The Paleozoic limestone immediately beneath the Jurassic section in Manitoba differs from that of the Reston formation in colour and composition. The colour is usually dark buff, and near the contact may have a reddish tint caused by colouring material derived from the Amaranth formation. The carbonate is dense to vuggy, and is usually more crystalline and less argillaceous than the overlying limestone beds. Many of the beds are highly dolomitic. Fossil fragments are common, particularly in the Mississippian section where crinoid stems are abundant. Electric and radioactive logs have pronounced charac-

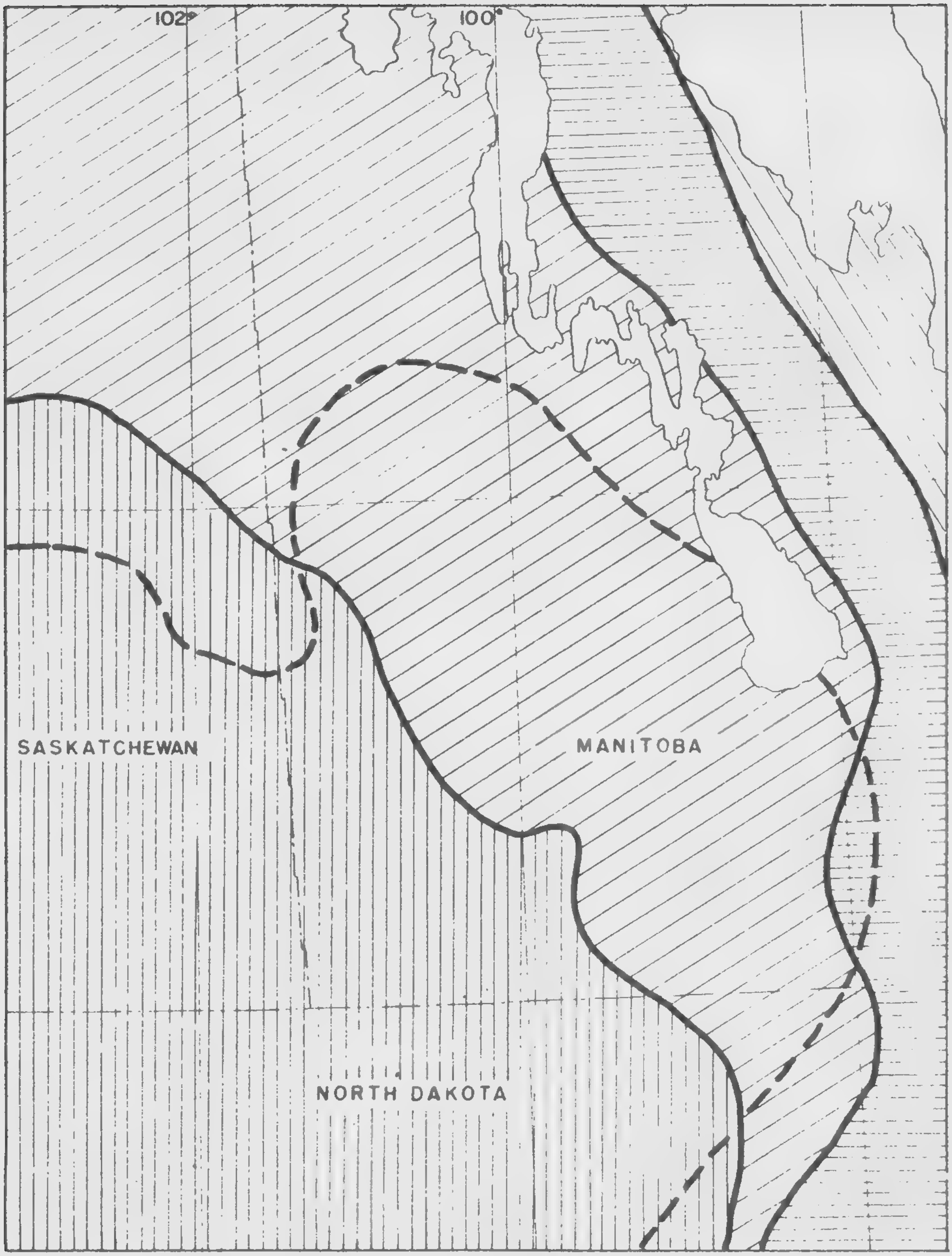

FIGURE 2 DISTRIBUTION OF SYSTEMS UNDERLYING JURASSIC ROCKS.

MISSISSIPPIAN SILURIAN
DEVONIAN ORDOVICIAN
LIMIT OF JURASSIC

teristics which aid in defining the contact with the Jurassic beds if well cuttings are poor.

AMARANTH FORMATION

In 1945, Wickenden, from a study of samples from several wells, suggested the name Amaranth formation for "an assemblage of red shale, gypsiferous beds, and calcareous rocks" which were found between rocks of known Devonian and Jurassic age.

The Amaranth formation consists of two distinctive units, the Lower and Upper Amaranth. The Lower Amaranth unit, containing dolomitic shales, some gypsum, and sand, is predominantly brick-red in colour. The Upper Amaranth unit, containing anhydrite, dolomite, and shale, is an evaporitic sequence overlying the red beds.

Lower Amaranth Unit

Definition

The Lower Amaranth contains the basal Jurassic beds. In Manitoba, the lower limit of the unit is the base of a detrital zone which lies on Paleozoic beds. The upper limit is placed at the base of the anhydrite and dolomite beds of the Upper Amaranth unit. The lower unit is well defined on the electric logs as a silty shale zone. This unit in Manitoba correlates with beds which some geologists suppose to be Triassic in age, but for reasons discussed later the section is considered to belong to the Jurassic system.

Distribution and thickness

Extending farther to the northeast than any other Jurassic unit, the lower Amaranth unit is one of the more widespread of Jurassic deposits, although it does not extend as far to the north as the Reston and Melita formations. The northeastern limit of the Lower Amaranth is not known as the zero isopach contour marks an erosional edge. It occurs throughout most of North Dakota, southern Saskatchewan, and southern Manitoba. To the east, in the vicinity of Amaranth, the red beds form the major portion of the Jurassic section. The areal extent of the Lower Amaranth unit is shown on the isopach map (Plate 4).

Rocks of the unit are missing in a small area around California Standard Wawanesa 3-1 (8-18W1), and only a thin

veneer occurs on a long peninsula-like area which extends southward to the vicinity of the Daly field. The thickest section of the unit is in the region midway between Lake Manitoba and the Saskatchewan boundary.

Although it is not present in some areas, the Lower Amaranth unit attains a maximum thickness of 125 feet in Manitoba, but a gradual increase occurs toward the central part of the Williston basin with a sharp increase occurring west of Hunt Shoemaker #1 well (Sec. 3, 157N, 78W). Near Williston, North Dakota, a maximum thickness of red beds of 525 feet is found, part of which, as discussed later in the chapter on correlation, probably is Triassic in age. The thickness of all the red beds has been included in the isopach map of the unit to show the increase in the southwestern corner of the area.

Relation to underlying beds

The red beds lie unconformably on rocks of Paleozoic and possibly Triassic age. Beds of succeedingly older age are found from southwest to northeast. In the Williston basin area, the underlying beds include the Amsden formation of Pennsylvanian age (Burk, 1954) and possibly rocks of Triassic age. Along Lake Manitoba, the red beds rest upon Devonian strata, and to the south lie on Silurian beds.

Description

The rock of the Lower Amaranth unit which has been recovered from the Amaranth Test Hole is similar to that found in the same unit in the Souris Valley Smart #1 (3, 32-1-25W1), Gould #1 (3, 14-2-29W1), and Dando #1 (4, 1-1-26W1) wells which are located in the southwestern part of the province. Hard massive reddish-brown dolomitic shale is the dominant lithologic type within the section. Beds of orange-pink crystalline anhydrite, which may be as much as one foot in thickness, occur near the top of the unit, but become less numerous and thinner toward the base. Veinlets of gypsum are also abundant in the upper portion. No beds of green shale occur, but locally, patches of pale green, dolomitic shale are found. The shale in the upper part of the section becomes more silty and sandy, and finally grades into fine-grained sandstone near the base. A breccia zone, one and one-half feet thick, composed of fragments of dolomitic limestone is found at the base. The fragments are as much as one inch in length.

The complete red bed section of forty feet has been cored in the California Standard Hargrave #15-16 (11-27W1) well. Breccia zones are common throughout, and a basal breccia marks,

extremely well, the contact with Mississippian rocks. This basal breccia is composed of red, green, and reddish-brown shale, fragments of anhydrite, and pinkish-white chert (pl. 1, fig. 1). The fragments are as much as two inches in diameter. Stratigraphically higher, beds of finely crystalline brownish-white anhydrite and brownish-green to brownish-red shale occur between breccia zones. A colour change in the core from brownish-red to bluish-white distinctly marks the top of the unit.

A section somewhat different than those described previously has been recovered in the core from the basal 29 feet of the Lower Amaranth unit in the California Standard Waskada 9-13 (1-26W1) well. Reddish-brown sandstone, well cemented and fine to medium grained, is interbedded with reddish-brown shale within the first four feet of section which lies above Mississippian rocks. The sand grains are well rounded and have a frosted and slightly pitted surface. The next 15 feet consist of interbedded reddish-brown and green shale which produce a "swirled" to mottled effect. Above this zone, which contains irregular patches and spots of finely crystalline anhydrite, green shales are interbedded with dark brown silt and dark grey to black shales in the same mottled manner. The black colour is caused by very finely comminuted carbonaceous material. Anhydrite also occurs in this zone.

A study of samples from numerous wells indicates that the descriptions given above are typical of the general lithology of this unit throughout the area. The red dolomitic shale becomes siltier and may grade into sand toward the base. The detrital zone is marked by chert and is found in almost every well. Evaporities are not abundant and occur in greatest thickness near the top of the unit.

In North Dakota, a change in colour and lithology occurs midway through the red beds above the Paleozoic rocks. The upper portion is composed typically of breck-red shales and sands with thin laminae and irregular patches of anhydrite. The lower zone contains medium grey shale, light grey sandstone, light olive-grey sandstone, and some sediments with a reddish colour. In Bakken #1 (Sec. 12, 157N, 95W) well, as logged by the North Dakota Geological Survey, a bed of yellow-grey limestone 40 feet thick occurs 110 feet from the top of the unit. In this portion of the California Nels Kamp #1 (Sec. 3, 154N, 96W) well, Seager (1942) recognized two members and stated that "The upper member is predominately composed of red argillaceous sandstone with rounded and frosted quartz grains, and red shales. The lower member consists of arenaceous red to brown shales and evaporites." In Manitoba, no carbonate beds were found in the Lower Amaranth unit.

PLATE 1

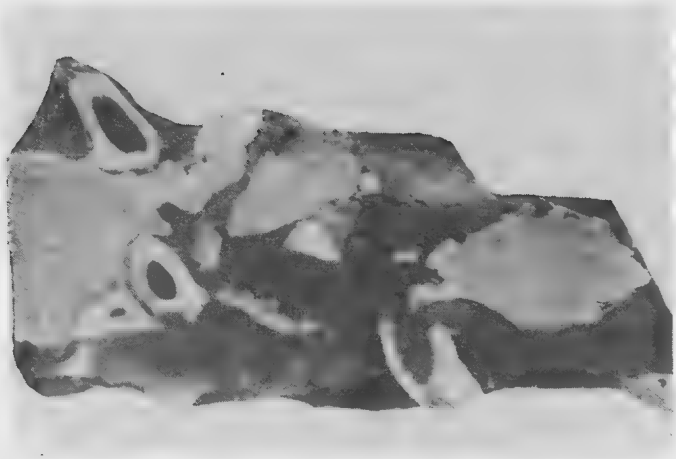

Figure 1. Breccia at the base of the Amaranth formation, California Standard Hargrave #15-16 well. Fragments of chert and anhydrite are enclosed in a shale matrix. (x 1)

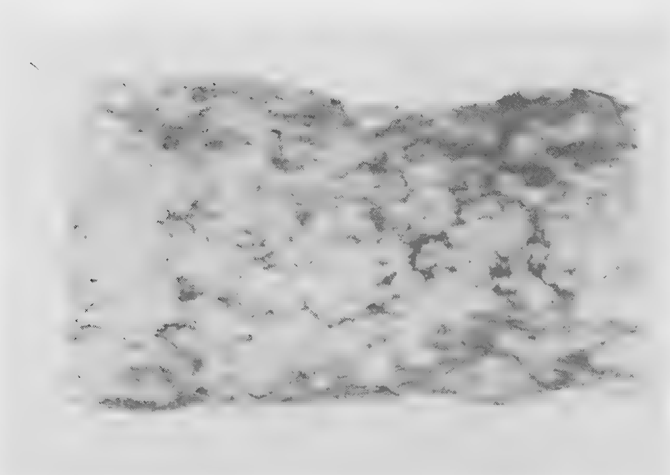

Figure 2. Irregular anhydrite masses in a shale matrix. Upper Amaranth unit, California Standard Hargrave #15-16 well. (x 1)

Upper Amaranth Unit

Definition

The Upper Amaranth unit is characterized by a high resistivity on electric logs, which sharply defines the unit. It is not so well defined in well cuttings because much of the anhydrite grinds to a fine paste and is lost in washing. The Upper Amaranth lies above the Lower Amaranth unit with apparent conformity. Anhydrite is the predominant lithologic type in this member.

Distribution and thickness

The areal extent of the Upper Amaranth unit is shown in Plate 5. No deposit or only a thin layer of sediments appears in three areas which correspond to areas of thin deposits of the Lower Amaranth unit.

Cretaceous sediments cover the Jurassic beds throughout most of the province but only a thick cover of glacial drift occurs over the bedrock of the Upper Amaranth unit in the vicinity of Amaranth.

Bailey (1951) suggested that extensive deposits of gypsum and anhydrite at Gypsumville, 80 miles northeast of Amaranth, may be related to the Jurassic evaporites. The deposit is 150 feet thick and is underlain by reddish argillaceous dolostone. A similar thickness of calcium sulphate is not known in Manitoba strata of either Devovian or Silurian age. Because Jurassic beds terminate as an erosional edge, this evaporite sequence could be a remnant outlier of the Amaranth formation. Because direct correlation cannot be made to the continuous beds of Manitoba, these beds have not been considered in the construction of any of the maps which accompany this report.

The thickness of the Upper Amaranth unit attains a maximum of 165 feet with the greatest thickness occurring in areas around Langford #1 (5, 29-14-14W1) well, and around Tidewater Bender Crown #1 (13, 11-12-5W2). As shown on the isopach map, no deposits were encountered in the F. H. Rhodes Murphy #1, (18, 163N, 65W) and California Standard Wawanesa #3-1 (8-18W1) wells. The Upper Amaranth unit in North Dakota decreases slightly in thickness with a relative increase in the thickness of the overlying formation.

Relation to underlying beds

The Upper Amaranth unit rests with apparent conformity on the Lower Amaranth. These two units are very closely associated, and the Upper Amaranth never occurs separately. A few wells near the northern limit of the Jurassic rocks contain red beds of the lower unit without the anhydrite of the upper unit.

Description

No complete core is available for the study of the Upper Amaranth unit, and a picture of the unit can be obtained only from samples and portions of the unit which were cored in several wells.

The upper 12 feet of the unit were recovered in the California Standard West Daly #8-29 (10-28W1) well. The basal six feet consist of bluish-white finely crystalline anhydrite with thin laminae of buff dense dolomite. The upper section consists of a brecciated zone composed of dolomite fragments which are as much as one-half inch in diameter, but the contact between the dolomitic matrix and the fragments is not always distinct. Bluish-white chert concretions which have a very irregular outline and commonly show concentric or radiating structure are abundant and are disseminated throughout the section.

Two short intervals near the top of the unit were cored in the California Standard Hargrave #15-16 (11-27W) well. The first interval consists of a bed of anhydrite and shale which in many respects has the appearance of a breccia. However, the fragments appear to have formed a continuous bed of anhydrite which has been slightly shattered (pl. 1, fig. 2). A few narrow fractures are filled with white satinspar. The lower cored interval consists of interbedded dense buff dolomite (which has a very salty taste) and bluish-white finely crystalline anhydrite.

Similar sections have been cored in the California Standard Linklater #2-21 (7-28W1) and Creekside Mitchell #1 (10, 32-9-27W1) wells. These consist of massive anhydrite with a few thin laminae of greyish-brown waxy shale and buff dolomite.

From the described core and from sample descriptions, the lithology of the Upper Amaranth was found to be very similar throughout the area. The unit is composed of massive beds of finely crystalline bluish-white anhydrite with some interbeds of shale and buff dolomite. The shales are greenish-grey, medium to dark grey, brown, and olive-green. Most of these are hard but toward the base of the unit, soft silty shales may be found.

The dolomite is generally dense but sometimes has a chalky appearance. Traces of vuggy dolomite occur in a few places. Small quantities of gypsum are frequently found in samples from the upper part of the section.

The Amaranth gypsum deposit, which is being mined one mile south of the village of Amaranth, was described by Brownell (1942) who stated that a continuous bed of gypsum was found at a depth of 92 feet under a cover of glacial drift. His description indicated that the deposit may be divided into three units; (a) an upper gypsum layer, 25 feet thick, (b) an anhydrite zone, 4 feet thick, (c) a lower gypsum layer, 9 feet thick. According to Brownell, buff domomitic limestone occurs in "narrow streaks and bands up to six inches thick, though on two occasions mining operations are reported to have removed lenses of limestone seven or eight feet thick and around twenty-five feet or so in horizontal extent," and the gypsum bed is "underlain by three feet of impure gypsum carrying much green clay and limestone (which) was followed by twenty-eight inches of green clay, below which (was) red shale." A detailed description of the quartz concretions in the gypsum and anhydrite is included in Brownell's paper. These closely resemble the concretions found in the West Daly well.

Other occurrences of gypsum were briefly outlined by Brownell (1931). A shaft near the Amaranth mine revealed a striated surface on the gypsum with the striations striking southeast. Brownell reported that a shaft in Charleswood went through a "fourteen-foot zone of gypsum in the form of boulders and irregular masses of gypsum underlain by a heavy clay." He continued, "The heterogenous and fragmental character of the gypsum point strongly to its having been transported there by glaciers, but that its source cannot be far distant is evident from the soft character of the material, which obviously could not withstand transportation for any great distance." No evidence of the rock occurring in place was obtained this far east.

RESTON FORMATION

Definition

The name, Reston, has been applied to rocks occurring in Manitoba and eastern North Dakota. The unit is characterized in this area by argillaceous to dense, light-coloured limestones, greyish-green and grey shales. In eastern Saskatchewan, significant thicknesses of sandstone occur in the equivalent stratigraphic horizon but farther west the formation grades into shale

and limestone.

Because of the persistent character of this unit and its fairly constant thickness, it has been chosen as the datum in the construction of the stratigraphic cross-sections (pl. 11, 12, 13).

Distribution and thickness

The Reston formation extends to the limit of the eroded Jurassic rocks throughout most of the area except near Lake Manitoba. If extrapolation of the isopach contours (pl. 6) is correct, the formation overlaps the edge of the underlying unit and extends farther north in Manitoba than any other Jurassic formation.

Ranging from 15 feet to 150 feet in Manitoba, the thickness of the formation reaches a maximum of 200 feet in the centre of the Williston basin. The maximum thicknesses in Manitoba occur in the north and south-central part.

Relation to underlying beds

The contact between the Amaranth and the overlying Reston formation appears to be unconformable. Fragments of bluish-white to milky white chert occur in well samples from the contact zone of many wells. A core from California Standard West Daly #8-29 (10-28W1) well contains an irregular contact between massive dolomite and an overlying breccia zone. The breccia consists of fragments of dark grey to blue, dense chert in a sandy matrix. Chert fragments attain a maximum diameter of one inch.

Description

The lower part of the Reston formation contains more shale beds than the upper part. These shales are light to dark grey, greyish-green, and occasionally reddish- to yellowish-brown. Stratigraphically higher in the section, limestone beds, which appear throughout the formation, are thicker and more numerous and the shale beds are less prominent. The limestone is dense, somewhat dolomitic, commonly argillaceous, very light buff to white, and often appears chalky. It is sandy in some zones. The lack of fossil fragments in this limestone contrasts greatly with the abundance of fragments in the limestone bands of the overlying shale formations.

The top of the formation is marked by an oolitic to sandy zone which developed to the greatest extent in the western part of Manitoba. Most of the core from this unit was recovered from the California Standard West Daly #8-29 (10-28W1) well. The oolites and sand grains are fine to medium grained, and are poorly consolidated by calcareous material. The rock is extremely porous. In the samples, the light buff oolites often occur as loose grains. This is shown remarkably well in the Imperial Birtle #1 (1-27-17-27W1) well where the sample appears to be a loose sand (pl. 2, fig. 1).

In the Virden area, the dense limestone zone of the Reston formation is missing, and the sandy oolitic limestone which is found above it on other areas lies directly on the Amaranth formation.

The only core from the massive limestone below the oolitic zone was obtained from the California Standard Waskada #9-13 (1-26W1) well. The core consists of buff-grey, dense to lithographic limestone.

Anhydrite and gypsum are present in samples from the Reston formation in several areas. Whether these occur in thin beds or in fractures is unknown.

MELITA FORMATION

As applied in this paper, the Melita formation is composed mainly of shales from which two units have been defined. The Lower Melita unit consists of varicoloured shales and thin interbeds of sandstone. Its lower limit is well defined by the contact with the underlying Reston formation. The upper limit of this member has been defined by lithology rather than by the changes in the electric log characteristics.

The Upper Melita unit contains green, calcareous shales with thin beds of coquina and dense limestones. Its upper limit is defined by a very strong electric log "kick" where shales of the Waskada formation are present. In other areas, sands of the Lower Cretaceous Swan River formation provide a sharp change in electric log characteristics and cuttings.

PLATE 2

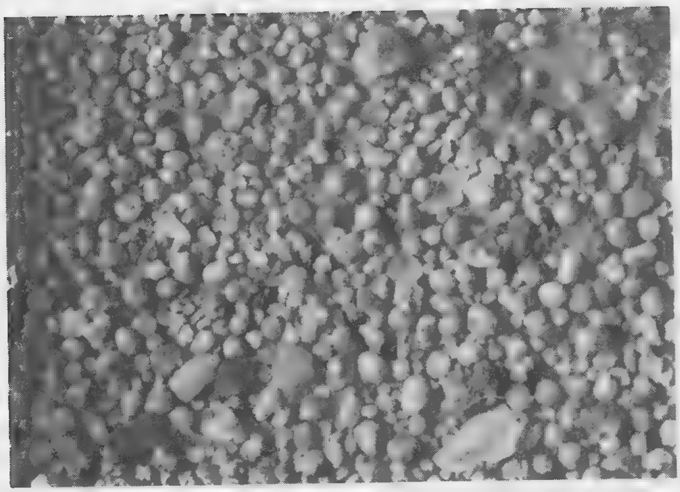

Figure 1. Oolites from the top of the Reston formation, obtained from samples of Imperial Birtle #1 well. (x 4)

Lower Melita Unit

Definition

Differentiation of the Lower Melita can be made with relative ease. Although the top is not marked by any pronounced break in the electric log characteristics, it can be determined from cuttings by the first appearance of varicoloured shales in this part of the section. The electric log character indicates a section with thin interbeds of sand, with the sand content increasing toward the base, particularly in the southwestern townships of Manitoba. Some question may arise in the determination of the division in the southern part of the province around the Boissevain and Whitewater wells, where an upper varicoloured zone is found, but these shales are succeeded by the normal greyish-green calcareous shales of the Upper Melita unit.

Distribution and thickness

The unit is found throughout Manitoba and can be traced into North Dakota and Saskatchewan. In Saskatchewan, further divisions of the member have been made but these lose their distinguishing features toward Manitoba. The Lower Melita decreases in thickness near Birtle, and is not present in the Grandview area.

A maximum thickness of 200 feet has been determined for this unit in the southwestern part of the province.

Relation to underlying beds

A disconformity occurs between the Reston and Melita formations. This is marked by a distinctive change in lithology with shales and sands resting upon oolitic and argillaceous limestones.

Description

Quartzose light brown sandstone is common at the base of the section in the vicinity of the Souris Valley McKague #1 (2, 27-1-27W1) and Anglo Coates #1 (13, 20-4-27W1) wells. The rock is loosely consolidated, and crumbles under slight pressure which results in loose quartz grains appearing in the samples. This loose sand resembles the Swan River sand, but has a distinctive brown colour and is better sorted.

Fifteen feet of this sand section have been cored in the Souris Valley McKague #1 well. The quartzose sand is fine grained, with thin laminae of dark grey shale, abundant muscovite, and numerous carbonaceous inclusions. The sand is well sorted and most of it is 100 to 150 mesh size.

Above the sand zone, the section consists mainly of shales which have a wide range of colour, marked by orange-red and light yellowish-green shades which distinguish this unit from the overlying Upper Melita unit. Other colours are greyish-green, brownish-grey, olive-grey, mustard yellow, and buff-brown. The lithology changes within short distances both laterally and vertically. Thin lenses of very fine-grained calcareous sandstone occur throughout the section. Some argillaceous limestone bands are present.

A thin band of medium- to dark-grey shale overlies the oolitic member of the Reston formation in the vicinity of the Daly field. This shale is extremely fossiliferous, and contains several zones of crushed clam shells. Some cuttings from this bed are found in the California Standard Ewart Province #4-14 (8-28W1) and Reston Beattie #7-27 (6-27W1) wells. As described by Kerr in an unpublished log of the Manitoba Mines Branch, the core from the Jean Cleland #3 (4, 22-20-25W1) well has a similar 3-foot band which contains abundant crushed Ostrea. Shell fragments have been found at the same stratigraphic horizon in several other wells in the area.

A zone of sand and shale in the Hargrave area has been included in the Lower Melita variegated shale unit. This zone occurs at the top of the section and the characteristics of the electric logs show interbedded sand and shale. The samples contain medium grey to greenish-grey, silty shale with traces of yellow-brown and orange-red shales. Very fine-grained white sandstone which is fairly well cemented with calcareous material also occurs in the cuttings.

A variety of fossil fragments were found in this zone. The broken guards of belemnites occur most frequently in this part of the section. A small gastropod, commonly pyritized, appeared in samples from several wells. Chara oogonia probably occur within a narrow band but cannot be definitely limited to position by cuttings. Smooth fragile ostracods are usually found with the other fossils in this manner.

To the east and north of the Daly field, the logs of the wells do not indicate the presence of this zone.

Upper Melita Unit

Definition

At the top of the Jurassic system, the shales are somewhat similar to those of the Melita formation, but thin sandstone beds are more abundant and limestone layers are lacking. Because of lithologic changes, a division of the Jurassic shales lying above the Lower Melita unit has been made. A pronounced electric log "kick" which marks a limestone band has been chosen as the dividing line.

Distribution and thickness

The Upper Melita unit has the most extensive distribution of the Jurassic units. Other units may have extended further but have now been eroded to their present limits. To the northeast, pre-Cretaceous erosion has stripped off any overlying beds and removed part of the unit.

A maximum thickness of 275 feet is attained in the southwest corner of Manitoba where overlying Jurassic deposits have protected this unit from erosion.

Description

In the southern part of the province, the top of the unit is marked by fossiliferous and dense limestone beds. These limestones occur as thin interbeds which probably are not continuous over a large area. Other limestone beds are found throughout the section but are not as abundant as at the top of the unit. The limestone is finely crystalline, dense, light grey to white if shell fragments are not present. The fossiliferous limestone has a mottled appearance caused by a light coloured matrix surrounding the darker carbonate of the shells. This limy zone does not appear in cuttings from wells in the northern part of Manitoba where erosion has probably removed part of the section.

The upper contact zone of this unit has been cored in the Souris Valley McKague #1 (2, 27-1-27W1) well and contains an eight foot bed of limestone. The limestone is composed of broken shells and contains a few complete fragile brachiopod shells. It is extremely porous and has a light brownish-grey colour. This fossiliferous limestone grades into a sandy limestone in the lower three feet which contains fine quartz grains and numerous, small pebbles of dense buff limestone. Below this limestone bed,

the core contains dark greyish-green shales which are calcareous and splintery to fissile. A one foot bed of light brown to reddish-brown calcareous shale occurs within the cored interval which also contains some greenish-white sandstone. This sandstone is quartzose, fine grained, and contains some glauconite.

The erosional contact of the Upper Melita unit with overlying Cretaceous sediments has been cored in two wells. In the California Standard Hartney #16-33 (5-24W1) well, the contact is marked by a finely brecciated layer. The overlying shales are medium to dark grey and contain thin laminae of glauconitic silt. The breccia matrix is calcareous, light greyish-green, and contains small fragments of buff to green shale. Some carbonaceous fragments are also present. A similar change from dark grey non-calcareous shales to greyish-green calcareous shales occurs in the Imperial Birtle #1 (1-27-17-26W1) well. A two-inch band of buff ironstone marks the break in lithology. Immediately below this, abundant fragments of pelecypods occur in thin shale bands. A few complete specimens of these fossils have been collected from the core.

Below the major limestone beds, the section consists of greenish-grey to brownish-grey shales which are slightly calcareous and commonly silty. Varicoloured shale cuttings occur within this unit in some wells but do not appear to represent a large thickness of this lithologic type except in the vicinity of Boissevain and Morden. A continuous variegated zone appears in the upper portion of the unit in this area. However, these shales do not contain such a large percentage of red shales as the Lower Melita unit, with brown and yellow shades being more prominent in the upper unit.

Thin interbeds of sandstone are not extensive. The sandstone is very fine grained, quartzose, and usually calcareous but may be kaolinitic.

In this section, thin lenses of anhydrite have sporadic distribution in location and stratigraphic position. Traces of anhydrite are found in the California Standard Findlay #9-26 (7-25W1) and Hartney #13-33 (5-24W1) wells. Anhydrite occurs with limestone near the top of the unit in Anglo Souris Valley McKee #1 (1-15-3-25W1) well where its presence is marked by electric log responses. This anhydrite differs from that of the Amaranth formation in having a pink to orange colour.

THE WASKADA FORMATION

Definition

As defined here, the Waskada formation contains all the beds of Jurassic age which lie above the Melita formation. The upper limit poses one of the major problems of this study. The overlying beds have a somewhat similar lithology and often have little difference of electric log characteristic. The top of the unit has been defined generally on the first appearance of grey-green calcareous bentonitic[1] shale. An upper zone of varying lithology has been included in the Jurassic system by the author, but this is questioned by some workers in the area who include these beds in the Swan River Formation. Definite determinations by paleontological evidence are lacking, and therefore the problem remains unsolved.

Distribution and thickness

Over most of Manitoba and Saskatchewan, the Waskada formation is absent. It occurs only as a tongue-like extension from the Swift deposits of North Dakota into the extreme southwestern corner of Manitoba as far north as the Daly field. The increased thickness in this area, as shown on the isopach map (pl. 7) of the shale units, is due almost entirely to the presence of the upper formation.

The thickness of the Waskada formation attains a maximum of 300 feet in North Dakota where 100 feet of Morrison formation are included by the writer. This decreases toward the erosional limits producing a saucer-shaped deposit. A maximum thickness of 175 feet is found in Manitoba but this decreases within a short distance to a knife edge toward the northeast and to the west. A marked decrease in thickness occurs in the Reston area, where only the lower beds of greyish-green shale are present. As the upper beds are missing in the region surrounding the Daly field, the deposits at that point form a thick wedge which cannot be directly correlated to east, west, or north. However, the thickness of the section increases in the vicinity of the Anglo Coates #1 (13, 20-4-27W1) well, and the strata of the Virden area are correlated with beds toward the south.

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[1] Bentonitic, as used here, implies a swelling quality and does not necessarily indicate a volcanic origin.

Relation to underlying beds

The Waskada formation lies above the Melita formation with apparent conformity. No evidence of an erosional contact has been seen in well cuttings or core.

Description

The lithology of the Waskada formation changes laterally and vertically within short distances. Shales are the predominant rock type but they vary in colour. Green bentonitic types are common and resemble those of the Melita formation. Minor beds of dark grey and black shales with small quantities of carbonaceous material occur. Some traces of red shale and ironstone are found in the cuttings. Sandstones, which are more abundant in this formation than in the underlying one, are usually white, very fine to fine grained, and are cemented with calcareous material. Pyrite and glauconite are frequently found in the sandstone.

In the Virden area, the formation has a fairly constant lithology. Shale of a greyish-green colour and calcareous nature is common at the base. Traces of reddish-brown shale are found near the upper contact. Ower (1953) reported that a thin red bed marks the top of the section. Fine calcareous sandstone occurs as thin lenses throughout the formation. A few thin beds of grey shale occur in this section, and the samples contain traces of bright orange and brown shales.

To the south, the beds contain abundant dark grey shales and some siderite pebbles. Red shales also are found in the upper part and greyish-green shales occur toward the base. Traces of plant fragments are seen in some samples. Some of the shale was examined in core from the McKague (2,27-1-27W1) well. The core consists of light greenish- to olive-grey calcareous shale which grades into grey siltstone.

OVERLYING BEDS

Jurassic sediments are overlain by sand and shales of Cretaceous age throughout the entire region with the exception of a narrow area along Lake Manitoba. Cretaceous sediments probably extended over this also, but apparently were removed by glacial erosion during Pleistocene times.

The contact between Cretaceous and Jurassic beds appears to be an angular unconformity, with older Jurassic beds appearing as the northeastern limit is approached. No thick breccia zone is found at the contact although core from the California Standard Hartney #16-33, (4-25W1) well revealed a thin band of finely brecciated shale.

The oldest Cretaceous sediments are included in the Swan River formation of Manitoba, the Blairmore formation of Saskatchewan, and the Dakota formation of North Dakota. This sequence contains one, and in some places two sandstone members and dark grey shale. The sandstone is fine to coarse grained and poorly consolidated. The quartz grains are fairly spherical, rounded, slightly pitted and frosted. The contrast between these grains and the sub-angular, fine-grained quartz in the Jurassic section is very marked. The sandstone is commonly pyritic, and contains fragments of Inoceramus. The shale is dark grey to black, somewhat silty, and is non-calcareous.

Some confusion has resulted from the usage of the formational name Swan River. The original formation was named in outcrop section near Swan River. Subsurface correlations were made, and the name applied to sands in southern Manitoba which occurred in a similar position. The information now available after more drilling reveals that these basal sands do not continue across the central part of Manitoba. Ower (1953) suggested that these basal sands in northern and southern Manitoba are not equivalent.

The beds of the Ashville formation lie above the Jurassic system north of the Daly field. These beds consist of dark grey to black, non-calcareous shales which are somewhat fissile. Sand is not present in very large quantities. Thin laminae and zones of light grey fine silt occur through the Ashville formation.

The distribution of Cretaceous beds overlying Jurassic beds is shown in Figure 3.

LITHOFACIES STUDY

An attempt was made to prepare lithofacies maps using the end-member concepts and dominant lithologic ratios as described by Krumbein (1948), and Sloss, Krumbein, and Dapples (1949). Clastic and sand-shale ratios were determined for each unit or formation which occurred in each well. The resultant values were contoured using the fundamental lithologic aspect triangle limits

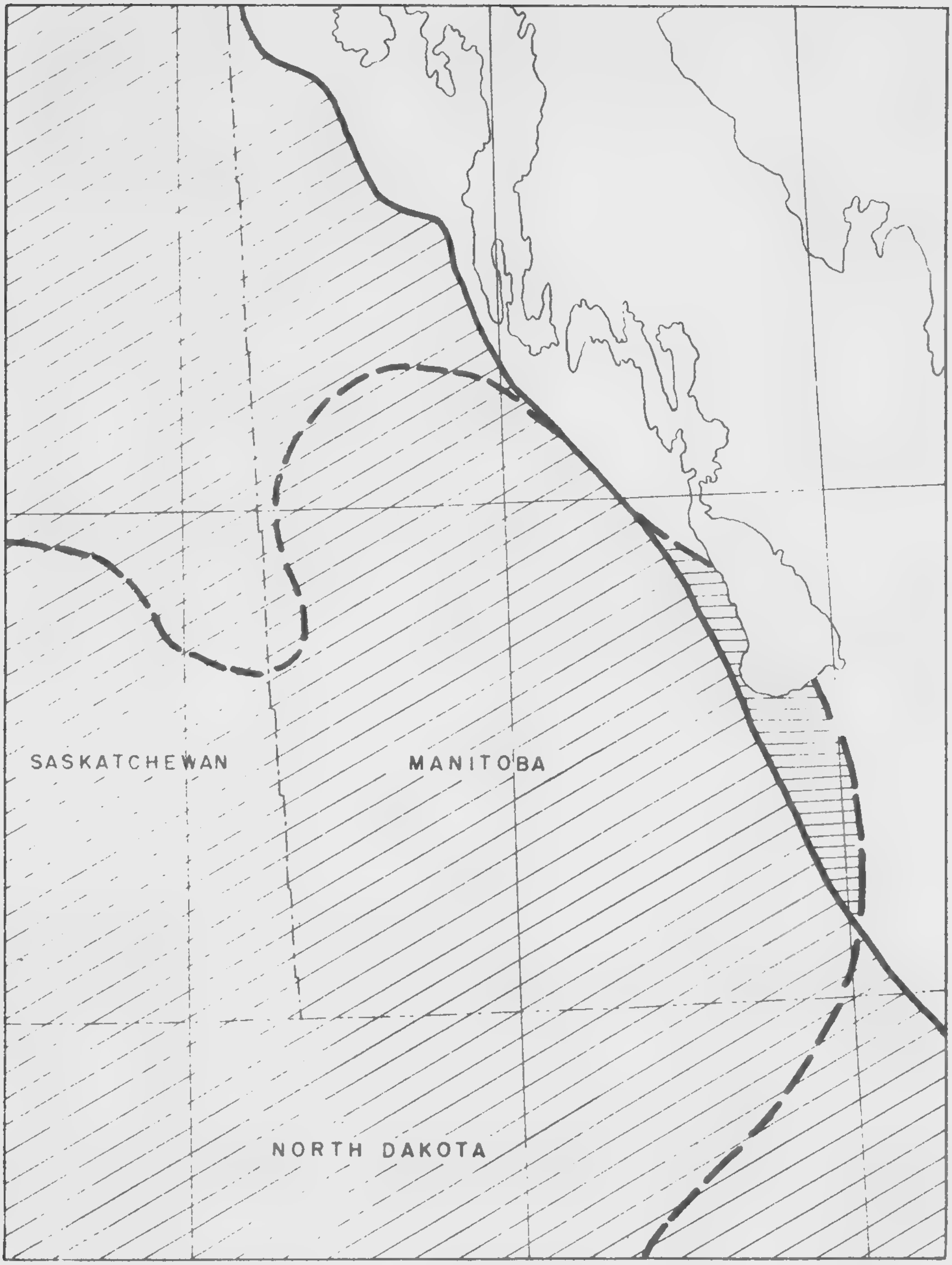

FIGURE 3. DISTRIBUTION OF CRETACEOUS BEDS OVERLYING JURASSIC BEDS.

LIMIT OF CRETACEOUS — CRETACEOUS
LIMIT OF JURASSIC — JURASSIC "OUTCROP"

which provided nine composite aspects for map representation of facies. No definite facies trends developed, and for this reason final maps were not prepared for inclusion in this paper.

It was found that any differences in lithology of the complete Jurassic section were obscured by the bulk thickness of the shale. In the Wawanesa area, the absence of the Reston and Amaranth formations was marked by ratios which indicated an all shale facies. By using smaller ratio limits, a trend west of Birtle and extending along the edge of the Jurassic deposits to the Grandview wells indicated a higher sand content, although the dominant lithology still remained within the sandy-shale facies. Elsewhere, the lithology falls within the limy-shale facies. Although control is extremely limited in the northeast, no variation from the dominant facies was noted.

No distinct variation in facies was found by contouring ratio values for individual formations. By using limestone, anhydrite, and shale as end members, a facies map of the Amaranth formation might produce some interesting trends, but without more detailed information on lithologic changes, preparation of such a map is not possible at the present time.

CHAPTER IV

PALEONTOLOGY

The scarcity of cored intervals in the Jurassic system of Manitoba limited the collection of macrofossils. Some microfossils were collected from well cuttings.

The abundance of shell fragments which are scattered through the well cuttings attest to the presence of the abundant fauna which has been found in outcrop and core of Jurassic rocks in other areas. These fragments are most commonly found in the shale units. No fossil evidence was encountered in any part of the Amaranth formation.

As the fauna is varied, an interesting study could undoubtedly be made if more material were available. Microfossils will probably be most useful in zoning the system as they are obtainable from well samples which compose the major part of the Jurassic record in this area. A study of these forms will require the abilities of a micropaleontologist.

One of the best correlating horizons is marked by the presence of Charophyte oogonia Alistochara. These occur within the Lower Melita unit, and are found in abundance in some well cuttings. A cored interval of the California Standard Hargrave #15-16 (11-27W1) well contained a one inch band of green calcareous shale with a large number of oogonia, but it is doubtful that a one inch band would supply the quantity of oogonia found in the samples. As the oogonia are found at slightly different stratigraphic horizons, they are probably distributed through about 25 feet of section.

Ostracods are associated with the Charophyte oogonia, and only infrequently are found separately. Both these types were recognized by Wickenden (1933) allhough no detailed description or illustrations of them have appeared in any of the discussions of the Manitoba Jurassic rocks.

Numerous fragments of brachiopods and pelecypods are found in the upper shale units. Two complete specimens of Gryphaea were recovered from the California Standard Hartney #16-33 (5-24W1) well, and fragments of rhynchonellid brachiopods were recognized in cuttings from a few wells. Some pelecypods identified by Kerr as Ostrea were found in core from Jean Cleland #1 (4, 22-20-25W1) well. Several good specimens of pelecypods which resemble Pleuromya were obtained from the core of the Imperial Birtle #1 (1, 27-17-26W1) well. These occurred near the upper limit of the Jurassic section.

Some traces of other fossils were also found in the samples. Broken belemnite guards are found within the variegated shale of the Lower Melita unit. Crinoid columnals have been found only in one well where they occurred within the shales of the Lower Melita. Other specimens which reveal the variety of fauna include a specimen of Dentalium, small gastropods, and a few unidentified formaminifera.

Wickenden has reported several species of foraminifera in Manitoba wells. Marginulina cf. sparsa (Terquem and Bethelin), Lenticulina cf. limata Schwater, and Guttulina were reported from the Manitou #2 (8,26-2-29W1) well.

The fauna indicates a Jurassic age for the beds in which they are found, but none of the specimens can be assigned to any specific time unit. The variety and distribution of the fossils show that environmental conditions were favorable for growth. Most of the genera represented in this collection lived in shallow waters. Charophyta are indicative of brackish to fresh water conditions. The pelecypod and brachiopod genera are types which lived in the neritic to littoral zone.

CHAPTER V

AGE AND CORRELATION

A discussion of the age and correlations of the Jurassic formations is given in this chapte Definite age relationships can only be made on the evidence of paleontology. Unfortunately, this is lacking in the Manitoba area, so only suggestions of a tentative nature can be made. A brief summary is contained in the correlation chart (page 6).

AMARANTH FORMATION

The Amaranth formation as defined by Wickenden in 1945 was not given a specific position in the geological record because no conclusive evidence of its age was obtainable. At that time, Wickenden could state only that the Amaranth formation was found between rocks of known Devonian and Jurassic age, because the presence of Mississippian rocks below the red beds in Manitoba had not been recognized. He tentatively assigned the Amaranth formation to the Jurassic period but pointed out that this formation resembled the Triassic and Carboniferous red beds of North Dakota. As will be discussed later, some doubt exists that some beds placed by geologists in the Spearfish formation of North Dakota are actually of Triassic age.

Other workers have correlated the beds that are equivalent to the Amaranth formation with the Gypsum Spring formation. Imlay (1947) stated, "The Gypsum Spring formation of the Wind River Basin of central Wyoming has been defined by Love as including 250 feet or less of gypsiferous beds disconformably underlying beds that have generally been referred to the Sundance formation. The lower part of the Gypsum Spring formation of central Wyoming is characterized by 50 to 125 feet of massive white gypsum underlain by a bed of red sandy shale. Its upper part consists of alternating beds of gypsum, red shale, dolomite, and limestone." Schmitt (1953) considered all the Middle Jurassic sediments as equivalent to the Gypsum Spring formation. He believed that the Amaranth belongs partly to the lower Jurassic and partly to the Big Snowy (Mississippian) group, and thought that no Triassic rocks were present in Manitoba and northeastern North Dakota. Bailey (1953) considered that the assemblage of red beds was Jurassic in age.

The beds of the Gypsum Spring formation of Wyoming are not continuous into North Dakota, but apparently pinch out on an arch. It is for this reason that the name Amaranth is used in preference to that of Gypsum Spring. However, it is believed that the Amaranth formation was laid down at the same time and under similar conditions that existed during the deposition of the Gypsum Spring formation.

From Manitoba, the red beds of the Amaranth formation have been traced southwestward into North Dakota and westward into Saskatchewan. The Saskatchewan beds are similar in thickness and in lithology. In this area, the red bed unit is known as the Watrous formation which is a new name proposed to replace the name Davidson.

To the south, the red bed sequence is placed in the Spearfish formation by the North Dakota Geological Survey. The type locality of the Spearfish formation was described by Darton (1899) in the Black Hills of South Dakota. He considered the Spearfish to be of Triassic age. Imlay (1947) stated that the Spearfish pinches out in North Dakota. Schmitt (1953) believed that the Amaranth formation of Manitoba belonged partly to the lower Jurassic and partly to the Big Snowy group, but from cross-sections of well logs, he placed the complete red bed section of North Dakota in the Triassic Spearfish. Milner and Hadley (1953) placed the complete Watrous (Davidson) formation in the Jurassic system.

As pointed out in the description of the red beds, the thickness of the unit increases greatly in the central area of the Williston basin. A change in lithology also occurs; the electric logs of the section show a change in characteristics from a silty shale to a sand section. From this evidence, the red beds of Manitoba are correlated with some beds which are believed to be included incorrectly in the upper part of the Spearfish formation.

The isopach maps of the red bed member and the anhydrite member of the Amaranth formation point out the very close relationship of these two units. Neither samples nor core indicate any unconformity between these two members which supports the theory that they belong to the same cycle of deposition. A major disconformity exists between Triassic and Jurassic rocks where known strata of these two systems are in contact. In the Manitoba section, the major disconformity occurs at the base of the red beds.

Recent work in North Dakota indicates that part of the red beds are now considered to be of Jurassic age. Towse (1954) stated that the lower Piper formation contains red shale and Gypsum, and appears to grade into the Triassic Spearfish formation.

From the evidence discussed in the preceding paragraphs, the writer believes that the red bed member of the Amaranth formation in Manitoba is of Jurassic age. It is thought that the basal section in North Dakota probably belongs to the Triassic period, and that the contact which would then occur within the sequence has not been recognized by workers in that area as an unconformity.

The Upper Amaranth unit can be correlated definitely from Manitoba into North Dakota and Saskatchewan, although an increase in the quantity of dolostone occurs in these areas. The thickness of the Upper Amaranth decreases in North Dakota, and in the centre of the Williston basin area the evaporitic phase apparently changed to more normal deposition of limestones and shales. This corresponds to the lower portion of the Piper-Sawtooth formation as recognized by Schmitt and the North Dakota Geological Survey.

In eastern Saskatchewan, the upper part of the section contains significant thicknesses of dolostone. The unit is called J-4B by the Petroleum and Natural Gas Branch of Saskatchewan. Milner (1953) included this in his Davidson (Watrous) formation, and considered it equivalent to the Gypsum Spring formation. Thus, the anhydrite unit is considered by many workers to represent basal Jurassic sediments.

Imlay (1949), who has made a thorough study of the fauna of the Piper-Sawtooth formation has placed the basal part as equivalent to the Bajocian stage of Europe. In his correlations, he indicated that the Gypsum Spring formation of Wyoming is equivalent to the basal beds of the Piper-Sawtooth formation.

As the Amaranth formation can be correlated directly with beds in North Dakota and Saskatchewan which are considered to be of early Middle Jurassic age, it is tentatively assigned to the Bajocian stage.

RESTON FORMATION

The Reston formation is not as characteristic in Saskatchewan where more shale beds occur between the limestones. Further west, the formation tends to lose its identity and is further divided. Southwestward into North Dakota, the formation retains its distinctive features, and the upper limit has been used by Schmitt (1953) for correlation purposes.

The Reston formation and the Upper Amaranth unit of this paper are included by Schmitt in his Piper-Sawtooth formation which he considers to be equivalent to the Gypsum Spring formation. Imlay (1949), however, correlating with paleontological evidence, placed the Gypsum Spring formation as equivalent only to the basal part of the Piper-Sawtooth formation of Montana. He indicated that the upper beds of the Piper formation are Bathonian in age, but the older Gypsum Spring formation is believed to be Bajocian in age. Schmitt does correlate his Piper formation with Cobban's Sawtooth formation in Montana, which was deposited in the Bathonian stage.

A hiatus in the Black Hills area including all of the Bathonian and part of the Bajocian stages is shown by Imlay to exist between the Gypsum Spring and Canyon Springs (basal Rierdon) member. This hiatus is represented elsewhere by limestones and shales which form the upper deposits of the Piper formation.

As the Reston formation is directly correlated with the upper beds of Schmitt's Piper-Sawtooth formation, it is considered equivalent to those beds laid down between the Gypsum Spring and Rierdon formations, and to be of Bathonian age.

The correlation of the Jurassic section above the Amaranth formation has been hindered by some disagreement by workers in correlating Saskatchewan formations with those of Montana (see Table 2). The Reston formation appears to correspond to most of units J-2B, J-3, and J-4A. The Gravelbourg formation (J-3 and J-4A, and the Upper and Lower Shaunavon (J-2A and J-2B), are correlated by Milner and Hadley with the Piper-Sawtooth formation. However, Francis (1954) indicates that only the Gravelbourg formation is equivalent. Thus, the contact between formations in Saskatchewan which may be equivalent to the Piper-Sawtooth and Rierdon formations is not considered by all workers to be in the same stratigraphic position.

TABLE 2

Correlation of the Jurassic formations in Saskatchewan

<table>
<tr><th></th><th></th><th>Francis</th><th>Milner</th><th>This paper</th></tr>
<tr><td rowspan="3">Vanguard</td><td>J-1A</td><td rowspan="3">Swift</td><td rowspan="2">Swift</td><td rowspan="2">Waskada</td></tr>
<tr><td>J-1B</td></tr>
<tr><td>J-1C</td><td>Rierdon</td><td rowspan="2">Melita</td></tr>
<tr><td rowspan="2">Shaunavon</td><td>J-2A</td><td rowspan="2">Rierdon</td><td rowspan="4">Piper</td></tr>
<tr><td>J-2B</td><td rowspan="3">Reston</td></tr>
<tr><td rowspan="2">Gravelbourg</td><td>J-3</td><td rowspan="2">Piper</td></tr>
<tr><td>J-4A</td></tr>
<tr><td>Watrous</td><td>J-4B</td><td>Gypsum Spring</td><td>Gypsum Spring</td><td>Amaranth</td></tr>
</table>

Correlation with the work by Vigrass (1953) provides more evidence for the solution of this problem. The Reston formation correlates with Vigrass's L-3 unit; the oolitic zone is equivalent to the L-2 unit; and the variegated shale section of the Melita formation is equivalent to his L-1 unit. Fossils collected from the L-1 unit by Vigrass do give some indication of a correct correlation. These fossils were identified by Imlay, who reports, " .... the presence of the brachiopod Lingula and numerous ostracods indicates that the beds are older than the Redwater shale (Oxfordian) and that they are equivalent to the Rierdon shale of Montana". Vigrass also reported that cephalopod collected from a limestone in Montana equivalent to his L-2 unit

was identified by Imlay as belonging to the Gowiceras subitum zone of the Rierdon formation, but that Laird believed the field evidence indicated it should be placed in the Sawtooth formation. From this evidence, the equivalence of Vigrass's L-2 unit to the Rierdon formation may be questioned. The oolitic zone in Manitoba which correlates with the L-2 unit has been included in the Reston formation. The division between Middle and Upper Jurassic beds has been placed at the top of the oolitic limestone of the Reston formation, and not at the top of the variegated shales of the J-2A unit as suggested by Milner and Hadley.

MELITA FORMATION

The shale beds of the Melita formation have been traced into Saskatchewan where they grade into sandstone. Near the centre of the Williston basin area in North Dakota, the Lower Melita tends to lose its distinctive characteristics.

The problem involved in placing the Lower Melita in its proper time zone has already been discussed. In review, the writer assigns the varicoloured shales to the Melita formation. The unit is equivalent to the Upper Shaunavon or J-2A formation of Saskatchewan, but for reasons given previously, this is considered to be Callovian rather than Bathonian in age.

The Upper Melita unit has been traced into North Dakota where it usually is present if any Jurassic sediments appear. The unit can also be correlated with the Saskatchewan section. The limestone zone which occurs at the top of the section persists into Saskatchewan, and a similar band occurs in the United States.

Those beds in North Dakota which are equivalent to the Upper Melita have been included by Imlay and Schmitt in the upper part of the Rierdon formation. In Saskatchewan, equivalent beds are known as the Lower Vanguard formation which is correlated directly with the Rierdon formation of Montana by Milner and Hadley and with the Swift formation by Francis. Vigrass (1953) collected numerous fossils which were of Callovian age from beds of similar stratigraphic position and lithology.

The Upper and Lower Melita units are considered to be equivalent to the Rierdon formation of Callovian age. This is in complete agreement with the work of Schmitt in North Dakota, but some disagreement exists over the correlation with time units as outline by Francis (1954) and Milner and Hadley (1953).

THE WASKADA FORMATION

The Waskada formation, having been removed by erosion, does not occur over parts of Saskatchewan and North Dakota. Because of this, lithologic correlations are somewhat difficult to make from one area to another.

All Jurassic beds of Saskatchewan which are younger than Callovian in age are placed in the Upper Vanguard formation which according to Hadley and Milner (1953) "includes both the non-marine Morrison formation and the marine Swift formation of Montana." A similar situation may exist in Manitoba where all the beds above the Melita formation have been placed in the Waskada formation. The Waskada formation is correlated directly with the Upper Vanguard formation.

Schmitt (1953) in his discussion of strata above the Rierdon formation described only the marine Swift formation in North Dakota. Towse (1953), of the North Dakota Geological Survey, indicated that non-marine beds above the Swift are recognized as the Morrison formation. The Morrison formation is considered to be Kimmeridgian to Portlandian in age, and represents continental sedimentation after the withdrawal of marine waters in Oxfordian times. The grey-green shales found in the Waskada formation of Manitoba are believed to be equivalent to the Swift formation of North Dakota. The varicoloured shales found at the top of the Jurassic section only in the extreme southwestern corner of the province may be equivalent to the Morrison formation. Further limitation of age relationships must await paleontological determinations.

CHAPTER VI

INTERPRETATIVE STRATIGRAPHY

From the description of the Jurassic sediments, including lithology, thickness, and extent, some generalizations of their depositional history can be outlined. A brief summary of events is included in this chapter.

UNDERLYING STRATA

Although much of the basin in the southwestern part of North Dakota probably developed during the deposition of Cretaceous sediments, some of the structural trends were apparently

also present throughout the Jurassic period. Along the Manitoba-Saskatchewan border, a long ridge with adjacent troughs extends southward. In the vicinity of Wawanesa there is a prominent dome, 150 feet high, on the Paleozoic surface. Another very gentle ridge in North Dakota has an east-west trend. The surface beneath the Jurassic sediments appears to be uniform on the western side of the elevated areas. Slopes dip gently to the southwest with no marked shelf areas adjoining the basin.

The dome near Wawanesa is believed to have been responsible for the non-deposition of red beds and anhydrite in the area surrounding the Wawanesa well. Other areas of non-deposition are also related to similar elevated surfaces. One of these is located along the Manitoba-Saskatchewan border around the Churchbridge and Madeline wells. The other area is in North Dakota around Murphy #1 (Sec. 18, 163N 65W) well. These areas apparently existed as islands or peninsulas during the deposition of the early Jurassic sediments, and undoubtedly had considerable influence on the sedimentation of the area. Although tectonism may have been involved in the original formation of these high areas, their present shapes were more likely controlled by pre-Jurassic erosion.

The differences in relief in the Hartney area has apparently been caused by erosional agents. A suggestion that the section revealed by the California Standard well were laid down in a down-dropped fault block is not considered because the underlying basal Devonian rocks can be correlated easily from well to well.

Two explanations involving erosion arise in consideration of this problem. The thicker deposits penetrated by the California Standard well may have formed in a solution cavity such as is found in karst topography. However, no breccia zones occur in the cored intervals, and these might be expected from the collapse of the caves. As the California Standard well contains 800 feet more of Jurassic sediments than the Royalite well, a cave of great depth would be required. No known caves have such a depth, and it seems unlikely that such existed in previous times. The most reasonable explanation is that the sediments were deposited in an old river valley or canyon. In either case, base level would have to be below the floor of the depression to provide gradient for such deep erosion. If this assumption is correct, a hiatus of considerable time and an uplift of considerable magnitude must be envisioned.

A topography similar to that found along the Manitoba escarpment formed by Cretaceous sediments is suggested for this region between the Mississippian and Jurassic periods. The canyon occurs along the erosional limits of the Mississippian beds and could be a typical feature associated with an escarp-

ment. Dissection by rivers would then explain the presence of Mississippian remnants. The fact is not overlooked that movements later than the deposition of Jurassic sediments have affected the area and produced structural trends. However, the elevated areas were present as shown by non-deposition around them, and it is believed that any structural movements have only emphasized these features.

AMARANTH FORMATION

Lower Amaranth Unit

The red beds, such as those found in the Lower Amaranth unit, have been the subject of much research during recent years because they occur as extensive deposits throughout the geologic record.

In summary, primary red soils are apparently coloured by ferric oxide formed under humid conditions and deposited under oxidizing conditions. Red beds may be the result of local reworking of the regolith or the reworking of older red beds.

The red colouring material of the Lower Amaranth unit may be derived from both sources. Devonian strata include the Ashern and Lyleton formations which contain thicknesses of brick-red, argillaceous dolostone, siltstone, and red shale (Bailey, 1953). As the Lyleton formation is missing over much of Manitoba, it may have been eroded in early Mesozoic time. The Ashern formation outcrops along Lake Manitoba, and erosion has apparently removed any thickness which occurred to the east.

If the assumption is correct that the unconformity below the Lower Amaranth represents the interval between Mississippian and Jurassic periods, sufficient time was available for the development of a deep regolith. Pennsylvanian times were sufficiently humid to provide favorable weathering conditions for the formation of red pigment. Permian and Triassic periods were more arid, but this would favor oxidizing conditions which would preserve the colour.

The stringers of anhydrite and gypsum which occur in the Lower Amaranth show that evaporating conditions existed at the time of its formation, and give support to the theory that the climate was hot and at least semi-arid. However, carbonaceous material found in the sediments reveals that the climate was not completely arid during the deposition of the red beds.

Deposition of the lower Amaranth unit is believed to have occurred on an irregular erosional surface because thick-

ness values change from place to place. Non-deposition on the island and peninsulas which are only about 150 feet above the general surface level indicates that the water was not deep. The presence of these features in the area would hinder normal circulation of water.

No coarse clastics are found in the unit which signifies that the surrounding land mass was low. The dolomitic nature of the shale is suggestive of a carbonate source, and probably the extended limits of the underlying Mississippian and Devonian beds supplied material to these Jurassic sediments.

A fringing lowland, similar to the present land area, is envisioned along the northern, northeastern, and southeastern edges of the site of deposition. Any rain in this semi-arid country would produce flash floods which would transport the regolith to the basin. Imlay (1949), described beds in a similar stratigraphic position, and stated, "These red beds and associated gypsum and dolomite are the initial deposits of a sea that spread eastward and southward around a large island in the area of central Montana early in Middle Jurassic time .... Bordering landmasses must have been very low, judging by the scarcity of sandy material and the general slight thickness of the deposits. Some of the red silt and clay may have been reworked from old red beds of Triassic or Permian age to the south and southeast. Other sources were probablv distant, because the presence of extensive masses of gypsum suggests a fairly hot and arid climate on the lands bordering the sea."

As indicated by lithofacies study, no facies changes were noted near the northeastern limits of the red beds. Such changes might be expected if the present limit is near that of the limit of deposition. Because of this, it is believed that the basal beds extended further northeast across Manitoba, but no estimate of the distance can be made. The possible presence of a Jurassic remnant at Gypsumville, 80 miles northeast of Amaranth, has already been mentioned.

Upper Amaranth Unit

The Upper Amaranth unit is closely associated with the red bed unit. The contact is conformable, and in the cores the only distinction is a colour change. It is concluded that the anhydrite and red beds formed in much the same invironment. Probably the arid conditions under which the red beds were deposited caused calcium and sulphate ions to be sufficiently concentrated so that they precipitated.

As suggested previously, normal marine circulation was hindered by the presence of several islands through the Western Plains area. Some connection with the open sea must have been present to allow water to carry in the quantities of salts required to produce the thicknesses which are present. Some of the calcium sulphate may have been derived from older deposits in Devonian and Mississippian rocks.

Recent investigations of the physical-chemical conditions which control the deposition of calcium sulphate give some clues to the history of the deposit.

Posnjak (1938, 1940) has shown that under normal pressures in aqueous solution calcium sulphate will be precipitated as gypsum unless the temperature is over 108°F, in which case anhydrite forms. If other salts are present in solution, the transition temperature may be lowered to 86°F. This range of temperature for any length of time is only found in the hotter climates of the world. If deposition occurs at lower temperatures, Posnjak stated that the product must be gypsum. If the calcium sulphate of the Upper Amaranth was deposited as primary anhydrite, then the climate was extremely hot.

Henderson (1953) reported on a thermodynamic treatment of Posnjak's data which gave transition temperatures for anhydrite in the presence of a saturated aqueous solution as a function of pressure. Henderson concluded from these investigations that "Gypsum should be converted to anhydrite at a depth between 2,000 and 3,500 feet in the presence of a water solution. In the presence of a salt solution, the transition probably would take place at shallower depth." He also indicated that conversion of anhydrite to gypsum should be expected if deposits were near the surface.

The almost complete absence of salt from these deposits also poses a problem. Under evaporating conditions, gypsum will be precipitated first but halite will precipitate when the volume is reduced to one-tenth the original (Pettijohn, 1949, p. 360), and should be expected to occur above gypsum or anhydrite. The lack of significant quantities of salt demands a very delicate equilibrium between the rate of precipitation and the rate of inflow of normal sea water.

King (1947), in a study of the deposits of the Permian Castile sea, noted that salt beds were not associated with those of anhydrite as might be expected from the large ratio of sodium chloride to calcium sulphate in sea water. He concluded that normal sea water flowed over some type of barrier, and being less dense remained on top of denser basin water which had become more

saline due to evaporation. Calcium sulphate was believed to have precipitated because of high salinity, but because the concentration of chloride never was sufficient, salt did not form. King suggested that the salt brine returned to the open sea by overflowing the barrier or by percolation through it, thus keeping the halite concentration below that at which precipitation would occur.

From the evidence of the physical-chemical investigations, the sulphate of the Amaranth formation was probably deposited under semi-arid conditions as gypsum. Later burial then caused the conversion of the gypsum to anhydrite. Where the present cover is less than 2,000 feet, the reconversion of anhydrite to gypsum can be expected. Some evidence supports this theory. A zone of brecciated anhydrite in the West Daly and Hargrave wells could have been caused by the resultant decrease in volume which accompanies the dehydration of gypsum. Fractures have been described which may be evidence of tension caused by the decrease in volume. The Amaranth deposit, as described by Brownell (1931), contains good evidence of the reconversion of anhydrite to gypsum. The presence of some salt is an indication that the concentration of brine in the area was quite high.

Imlay stated, "The widespread gypsum mass at the base of the Middle Jurassic probably represents the initial deposits of the Middle Jurassic marine transgression .... The large areal extent of the gypsum at the same stratigraphic position suggests that it was formed nearly simultaneously in a single body of water rather than in numerous lagoons, that the depth of water was exceedingly shallow and uniform throughout a large area, and that the climate was so arid that few streams entered the sea." He also pointed out that islands formed partial barriers to normal marine water.

Two basins of deposition as indicated by the isopach map of the Upper Amaranth (pl. 5) occur in Manitoba, and appear to have had topographic sills. The isolated conditions would be more favorable to the deposition of the evaporites than the centre of the main basin where concentration of brine would not be so great. The theory is substantiated by the lithology in the centre of the Williston basin where limestone beds take the place of the anhydrite beds.

The edges of the red beds and anhydrite are controlled be erosion throughout much of the region. Along the northern edge, the Reston formation laps over the underlying units and possibly protected the depositional edge from erosion. However, as indicated elsewhere, a disconformity is postulated between these formations, and erosion which probably occurred after the

deposition of the Amaranth likely removed the edge of that formation. Thus, the limit of the formation is believed to be erosional and is not thought to mark the edge of the first Jurassic seas.

RESTON FORMATION

A return to normal marine conditions toward the end of Middle Jurassic time resulted in a sedimentation change from evaporites of the Amaranth formation to the shales and limestones of the Reston formation. The greater supply of clastics indicated by the presence of the shale beds at the base of the Reston formation suggests that the land areas were slightly higher than previously and were supplying greater quantities of weathered material to the basin. However, as the thickness of the formation over the entire area is relatively uniform, no large scale tectonism is believed to have occurred at that time.

Toward the centre of the basin, the Reston formation increases in thickness but the thickness of the Amaranth formation decreases. This may be attributed to deeper water in the middle of the basin which contained lower concentration of sulphate ions and which favored the deposition of carbonate. If this hypothesis is correct, no hiatus occurs between the Amaranth and Reston formations in southwestern North Dakota. No division between these is recognized in the Williston area where gypsum and anhydrite are almost completely lacking, and shale and limestone are predominant. Schmitt (1953) placed the beds of the writer's Upper Amaranth unit and Reston formation within his Piper formation. It is suggested that the Reston and Amaranth formations intertongue near the centre of the Williston basin, and that the unconformity between the formations in Manitoba disappears in the United States.

If no unconformity is postulated between the Amaranth and the Reston formations, the evidence of the hiatus in the Daly field must be explained. As described in Chapter IV, the oolitic limestone found normally at the top of the Reston formation rests on an erosional surface of the Amaranth formation in this area. As the sea in the region was shallow, it is possible that this area was sufficiently high during the deposition of the argillaceous limestone to suffer erosion. Inundation toward the end of the deposition of the Reston formation could have been caused by slight flexure associated with the tectonic movements which finally resulted in the retreat of the Middle Jurassic seas.

The hiatus in the Daly area may also be explained by postulating that the oolitic limestone member belongs to the Melita formation rather than to the Reston formation. If so,

the period of non-deposition between Middle and Upper Jurassic would provide ample time for the removal of any of the Reston formation which may have been present. An oolitic limestone unit in a similar stratigraphic position in Montana has been placed in the Rierdon formation by Imlay, although in published reports on the Williston basin area, the oolitic limestone is placed within the Piper formation.

On the cross-sections (plates 11, 12, 13,) which are included in this report, the oolitic limestone member has been placed within the Reston formation because electric log characteristics indicate a close association with the underlying argillaceous limestone. This criterion may be proven to be in error by paleontological evidence which is not available at present.

The argillaceous nature of the limestones is thought to indicate shallow water deposition. Precipitation could be caused by the insolubility of carbonate ions in warm waters and by organisms which found favorable conditions for growth in such environments. As oolitic texture is characteristic of shallow, strongly agitated water (Pettijohn, 1949, p. 301), the zone at the top of the formation is an excellent indication of shallow water. The well sorted sand associated with the limestone further substantiates the belief in shallow water conditions.

The carbonate sequence may have been derived from two sources. The shallow conditions, which are indicated by these deposits, would favor a concentration of carbonate ions which would be precipitated as limestone under the proper physical-chemical conditions. Much of this may have come from the circulating sea water. However, great thicknesses of Devonian and Mississippian rocks in the region have been eroded and these rocks probably were a major source of carbonate. The unfossiliferous nature of the unit may indicate fairly high saline conditions.

If the underlying calcium sulphate beds were deposited as gypsum, the resultant shrinkage which accompanied the recrystallization to anhydrite, would cause tension fracturing in the overlying Reston formation. These fractures would provide good channels for release of pressure on the sulphate with resultant movement upward. This seems to be the most probable explanation for the vertical veins of gypsum which are found in the Piper formation.

MELITA FORMATION

Other than the distinctive change in lithology, no evidence for a break in the sedimentary record was noted at the contact of the Reston and Melita formations. A hiatus exists between

the Middle and Upper Jurassic sediments elsewhere, and should be expected in this remote area which would be the first to suffer erosion as the Middle Jurassic sea retreated toward the northwest.

A possibility exists that the oolitic limestone placed in the Reston formation actually belongs to the Melita formation. The contact of this oolitic limestone with the Amaranth formation in the Virden area has been described, and contains good evidence of an erosional unconformity which may have developed after rather than before the deposition of the Reston formation. Further evidence is required from an area where the oolitic limestone lies above the dense Reston limestone before any final conclusions can be made.

The edge of the Melita formation has suffered erosion, and thus no definite limit of the earliest Upper Jurassic seas is known. The Lower Melita, however, appears to pinch out in the northern part of the map-area, and probably marks the limit of the first invasion of these marine waters. The Upper Melita beds extend further north, and may represent one of the most widespread transgressions of the Jurassic seas.

The basal Melita deposits formed in a transgressing sea consist of sandstones with sub-rounded, slightly frosted grains. These sandstones, which do not occur everywhere, appear as thin deposits which filled irregularities in the surface of the Reston formation.

During early Middle Jurassic time, the conditions of deposition of the Lower Melita unit apparently varied. The chara and ostracods found in the unit indicate that these sediments were laid down in fresh to brackish water. However, these conditions did not persist throughout all the period of deposition because the presence of belemnites and crinoids is evidence of marine waters. Probably fluctuations from marine to non-marine conditions occurred. <u>Lingula</u> and <u>Gryphaea</u> are typical of the neritic to littoral environments, and serve as further evidence of shallow water which would not require much tectonic activity to oscillate from marine to terrestrial environments.

Further deepening of the basin during the deposition of the Upper Melita resulted in more constant marine conditions. The silty shales, fossiliferous and argillaceous limestones, and quartzose sandstone suggest that the water was still comparatively shallow.

The limestone bed at the top of the unit, composed of shell fragments and oolites, is indicative of very shallow condi-

tions, and may be considered as the final sediments deposited by the Callovian sea as it withdrew from the interior region.

No evidence for an unconformity between the Waskada and Melita formations has been noted in Manitoba, and to date none has been reported from Saskatchewan. Although an unconformity does exist between the formations in Montana and Wyoming, the first Upper Jurassic sea may have not completely withdrawn from the more northern areas.

The sand samples from the Melita formation contain few diagnostic heavy minerals. The lack of these may be attributed to the reworking of older sedimentary beds, to a long period of weathering, or to intrastratal solution. The well sorted nature of this sand lends support to the belief in a long period of movement, probably by wave action. The angularity of the grains may be attributed to the breaking of larger grains during movement in the littoral zone.

The pyrite found in the sand is of authigenic origin. It forms euhedral cubes, and often serves as a cement in the consolidation of the sand grains. Reducing conditions are suggested by the presence of pyrite, indicating that the circulation of the sea water was not particularly good, thus resulting in the partial stagnation of the water in this area.

WASKADA FORMATION

The Waskada formation, characterized by sands and shales, lacks any major carbonate deposits. This condition may have been caused by the more positive tendencies of the land areas in the region. These positive tendencies were related to the first tectonic activity which finally culminated in the major diastrophism of Jurassic times within the Cordillera.

In late Jurassic time, the withdrawal of the sea toward the west led to the accumulation of clastics under continental conditions. As pointed out before, some of these deposits may be of Lower Cretaceous age as the time of invasion of the first Cretaceous sea is not definitely known.

The pattern of the Waskada formation in this area may be attributed to two causes. As other workers in the general area have indicated, deposition of this formation was not as extensive as the

lower units. Thus, only an elongated trough of sediments may have formed in Manitoba. This narrow area may also be an erosional remnant left after weathering had truncated the Jurassic deposits to the north and northeast. The structure contour map drawn from data on the top of the Jurassic (pl. 10) does not show any irregularity in this area, and favours the hypothesis of a tongue-like extension of the last Jurassic sea. Erosion has, however, removed the upper beds of the Waskada formation in the Reston area.

Schmitt (1953) described the Preuss unit which occurs between the Rierdon and Swift formation in the centre of the Williston area. This formation is not recognized within Manitoba. Schmitt believes that it was very limited in its extent. If this is correct, a disconformity representing the period of deposition of the Preuss formation does exist between the Melita and Waskada formations.

Marine conditions are believed to have existed during the deposition of the first Waskada shales. These were succeeded by more stagnant waters with the resultant formation of glauconite, siderite, and pyrite. Probably deposits of terrestrial origin occur at the top of the formation but definite proof is lacking.

SUMMARY OF GEOLOGICAL EVENTS

Pre-Jurassic

Throughout Manitoba and southward into North Dakota, a period of erosion followed the deposition of Mississippian strata. In Manitoba, the unconformity which is found at the top of the Mississippian beds represents an interval from the end of the Mississippian deposition to early Middle Jurassic time. During this interval, erosive forces were active throughout the Western Interior region. In the centre of the Williston area and in South Dakota, deposits of Pennsylvanian, Permian, and Triassic ages are found. However, no marine transgressions of these ages are believed to have extended as far as Manitoba. The Triassic strata have a terrestrial character and possibly were deposited over a wider area than that in which they now occur. Any beds that may have formed in Manitoba during this time have apparently been removed by erosion.

The conditions during the Pennsylvanian period were humid and warm. More arid conditions during Permian and Triassic

time would result in less weathering, but the environment would favor the preservation of residual iron compounds which gave the colour to the red beds.

Lower Jurassic

The first deposits in the region during Jurassic time were formed in two entirely different environments. In Alberta, the first marine transgression deposited the Fernie formation. These sediments record the invasion by an arctic sea which occupied a narrow trough along the present Alberta-British Columbia border. South of Montana, the Navajo and Nugget formations were deposited, and these are believed to be aeolian sediments laid down in an arid region (Imlay, 1949).

As no record of Lower Jurassic deposits have been found elsewhere in the Great Plains region, most of it was apparently above sea-level.

Middle Jurassic

A second marine invasion which occurred in early Middle Jurassic times apparently came along the same Alberta trough but extended further south and east. This sea was very shallow, and flood plains or lagoons occurred along the margins.

Residual material was carried into this basin, covering the erosional surface of Paleozoic rocks. Irregularities of the surface were soon filled, and widespread red beds composed of fine sandstone and silty shales developed in the area. Normal circulation of sea water was hindered by the numerous remnants of the old limestone beds. The remnants of Mississippian rocks left near the erosional edge of the deposits in Manitoba influenced to a great degree the deposition of the basal Middle Jurassic sediments. Under the restricted conditions, some calcium sulphate began to precipitate around the perimeter of the basin. A maximum thickness of 175 feet of gypsum and dolomite was deposited. In the centre of the basin, limestone deposits indicate that the sulphate ions were less concentrated. A very delicate balance between inflow and evaporation must have been maintained during the deposition of the gypsum in the upper part of the Amaranth formation to produce the thickness which is present. The climate at this time is thought to have been quite hot and arid.

An unconformity between the Amaranth and Reston formations apparently represents a withdrawal of the Middle Jurassic

sea from the areas most remote from the connection with the open sea. The intertonguing of beds in North Dakota which are equivalent to the Amaranth and Reston formation suggest that the deposition in the west was more continuous.

This retreat was followed by more widespread seas. Tectonic activity resulted in more normal circulation of sea water which produced argillaceous limestones and shales. The area remained comparatively stable throughout the remainder of Middle Jurassic time. At the end of Middle Jurassic time, the waters became shallower, forming ideal conditions for the production of oolites. Finally, the sea withdrew entirely from the area.

Upper Jurassic

Early deposits of Upper Jurassic age consist of varicoloured shales which carry both marine and non-marine fossils. The seas were probably shallow, and conditions varied from marine to terrestrial along the borderland for a considerable period.

Further deepening of the basin resulted in widespread inundation and the formation of marine sediments. In Manitoba, the deposits are typical of shallow water and contain abundant fossils. The withdrawal of this third transgression once more produced conditions favorable to the formation of oolites. A complete withdrawal may not have occurred in the Western Interior where evidence of a distinct disconformity is lacking. Imlay (1949) stated, "Deposition appears to have been continuous, or nearly continuous, from Callovian into Oxfordian time except over an extensive area of uplift in Montana and northern Wyoming."

The final invasion during the Jurassic period which occurred in the Oxfordian stage was not as widespread as the previous one. Glauconite and pyrite indicate that conditions were somewhat brackish.

The withdrawal of marine waters at the end of Oxfordian time left the area subject to erosion with subsequent deposition of terrestrial sediments. Much of the Waskada formation was removed, and the depositional edges of earlier formations were eroded. As the interval includes Kimmeridgian and Portlandian stages, the quantity of material removed from one place and deposited elsewhere may have been fairly large.

CHAPTER VII

ECONOMIC CONSIDERATIONS

GYPSUM

Gypsum has been mined from the Amaranth formation since 1929. In that year at Amaranth, Western Gypsum Products, Limited sank a shaft through approximately 100 feet of glacial drift to reach the deposit. The yearly production for the last three years has averaged 80,000 tons.

Any further plans for development of the deposits other than in the immediate vicinity of the town of Amaranth, must take into consideration the depth and type of overburden. As indicated in Figure 5, the Amaranth formation occurs beneath glacial drift along a very narrow band; Jurassic and Cretaceous sediments occur over the deposits in most of Manitoba. The pressure of the overlying rock may be sufficient to prevent anhydrite changing to gypsum. The completeness of hydration other than at Amaranth is not known. As the overlying beds are shales, the penetration by surface water will have been hindered. Thus, gypsum does not likely occur in commercial quantities except under areas of comparatively light cover.

PETROLEUM

To date, commercial oil production has been obtained only from formations in the Mississippian system of Manitoba. In the Jurassic, oil saturation has been found in some basal sections of the Watrous formation, but none has yet proved of commercial importance. The occurrence of oil in the Wapella field of eastern Saskatchewan, 25 miles west of the Manitoba border, in Jurassic and Lower Cretaceous sands, lends encouragement to the search for oil in equivalent beds in Manitoba.

Although sand is abundant within the Jurassic beds, few well developed zones of sandstone were found. The best zone occurs at the top of the Lower Melita unit in the Hargrave area.

In the vicinity of Waskada, sandstone at the base of the Melita formation is quite porous. These zones do not extend for any distance, and appear to be only lenses. A very porous zone is found in the sandy, oolitic limestone at the top of the Reston formation. This zone is fairly extensive, and would form a good reservoir. However, no trace of oil was found in the samples examined.

Stratigraphic traps may be formed by the numerous pinch-outs of formations and zones. These are most pronounced along the western edge of the lobe of Jurassic sediments which extends into northern Manitoba. The sand content increases also in this area, which makes conditions more favorable for oil accumulation.

Petroleum, recovered from Mississippian beds in Manitoba, in many cases occurs immediately below the contact with the Amaranth formation. If suitable sand zones exist at the base of the Amaranth formation, oil could have migrated upwards into these beds. However, sand found in the Amaranth formation is very silty and shaly, and would not form favourable reservoir rock.

CHAPTER VIII

GENERAL CONCLUSIONS

1. Rocks of Jurassic age extend from that part of Manitoba included in the Williston basin area northeastward into Manitoba as far as Lake Manitoba and Lake Dauphin, and older beds are truncated in this direction.

2. An unconformity occurs at the base of the Jurassic system.

3. Although Cretaceous rocks do not lie above Jurassic beds along a narrow band which extends from Lake Dauphin, along Lake Manitoba to the International border, no exposures are visible because of the thick cover of glacial drift.

4. The Jurassic system may be divided into four formations, which are from the base upward; Amaranth, Reston, Melita, and Waskada. These represent four invasions by marine waters.

5. An assemblage of gypsiferous red beds, anhydrite, and dolomite comprise the basal Jurassic beds, and are included in the Amaranth formation which was deposited under restricted conditions in Bajocian time. The formation is correlated with the Gypsum Spring formation of Wyoming.

6. The Reston formation, of Bathonian age, consists of shales, argillaceous and oolitic limestones which are equivalent to the upper Piper-Sawtooth formation, the Gravelbourg, and Lower Shaunavon formations of Saskatchewan.

7. Varicoloured shales and greyish-green marine shale dominate the Melita formation which is correlated directly with the Rierdon formation of Callovian age in Montana. Equivalent Saskatchewan beds have been included in the Lower Vanguard and Upper Shaunavon formations.

8. The Waskada formation contains beds which may range from Oxfordian to Portlandian in age. It is correlated with the Swift and Morrison formations of the United States, and the Upper Vanguard formation of Saskatchewan.

9. An erosional unconformity exists between the Jurassic and the Cretaceous systems. The Swan River sands are believed to occur above and not below this unconformity as suggested by some geologists.

10. Lithofacies studies in this limited area only emphasize that the lithology is quite constant, and is typical of stable to unstable shelf conditions.

11. Sand studies reveal that no marked change in sand types occurred in the Jurassic period. Sorting was excellent, indicating that the sediments were well reworked before final deposition.

12. Heavy mineral studies suggest that source rocks are to be found in igneous and metamorphic terrains as well as in the sedimentary areas.

13. In Manitoba, gypsum is the only product of economic importance which is at present obtained from the Jurassic system. Further exploitation will, of necessity, be confined to the "outcrop" area.

14. Although no indications of petroleum have been found in Jurassic strata in Manitoba, except in the basal Amaranth, there exist stratigraphic traps and sandstone lenses which could be reservoirs. Much of the northern area of Jurassic sedimentation is relatively unknown, and may contain thicknesses of sand in which oil could accumulate.

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APPENDIX I

WELL DATA

No.	Company	Well Name	Location
A		Amaranth deposits	Near Lake Manitoba
1		Red River Hepner #3	3-1-5-2 WPM, Man.
2	A. R. Coutts	Port. la Prairie #1	3-9-12-7 WPM, Man.
3	Hart Green	Wakely #1	1-28-4-4 WPM, Man.
4	Pembina Val.	Comm. Manitou #2	8-26-2-9 WPM, Man.
5	Souris Val.	Gordon White #1	5-14-1-28 WPM, Man.
6	Cal-Stan*	Ewart Prov. 4-14	4-14-8-28 WPM, Man.
7	Cal-Stan	Daly 15-1	15-1-10-28 WPM, Man.
8	Cal-Stan	W. Daly Prov. 8-29	8-29-10-28 WPM, Man.
9	Cal-Stan	Elkhorn 7-8A	7-8-11-29 WPM, Man.
10	Imperial	Birtle #1	1-27-17-26 WPM, Man.
11	Imperial	Madeline #1	16-18-18-29 WPM, Man.
12	Imperial	Foxwarren	16-32-19-27 WPM, Man.
13		Jean Cleland #3	4-22-20-25 WPM, Man.
14	Cal-Stan	Hartney 16-33	16-33-5-24 WPM, Man.
15	Cal-Stan	Wawanesa 3-1	3-1-8-18 WPM, Man.
16	Man. Gas	Brandon Coutts #2	14-16-10-19 WPM, Man.
17	Langford Oil	Langford #1	5-29-14-14 WPM, Man.
18	Shell Oil	Swan River #2	13-3-35-29 WPM, Man.
19	Cal-Stan	Spruce Woods ST#1	13-12-10-17 WPM, Man.
20	Cal-Stan	Tilston 5-32	5-32-5-29 WPM, Man.
21	Cal-Stan	Waskada 9-13	9-13-1-26 WPM, Man.
22	Cal-Stan	Spruce Woods ST #3	10-4-8-15 WPM, Man.
23	Cal-Stan	Spruce Woods ST #2	1-20-9-14 WPM, Man.
24	Royalite	Two Creeks #1	2-3-13-27 WPM, Man.
25	Brit.-Am.	Gilbert Plains	16-18-24-21 WPM, Man.
26	Brit.-Am.	Grandview #1	16-30-24-23 WPM, Man.
27	Petcal	Turtle Mtn. #1	10-26-1-20 WPM, Man.
28	Cal-Stan	Reston Beattie 7-27	7-27-6-27 WPM, Man.
29	Brit.-Am.	Grandview #3	16-25-25 WPM, Man.
30	Petcal	Linklater 3-29	3-29-7-28 WPM, Man.
31	Brit.-Am.	Grandview #4	13-34-26-23 WPM, Man.
32	Cal-Stan	Findlay 9-26	9-26-7-25 WPM, Man.
33	Souris Val.	McInnes #1	8-20-4-25 WPM, Man.
34	Royalite	East Hartney #1	7-27-5-24 WPM, Man.
35	Royalite	Scarth #1	14-19-8-26 WPM, Man.
36	Cal-Stan	Treat Province	15-29-15-28 WPM, Man.
37	Baysel	Bruxelles 1-27	1-27-6-11 WPM, Man.
38	Souris Val.	McKague 27-2	2-27-1-27 WPM, Man.
39	Baysel C. S.	Hargrave 13-15	13-15-11-27 WPM, Man.
40	Baysel C. S.	Sharpe Lake 3-27	3-27-1-22 WPM, Man.
41	Baysel C. S.	Boissevain 3-20	3-20-3-19 WPM, Man.
42	Imperial	Bluewing Lake	13-4-24-27 WPM, Man.
43	Anglo	Skelton 4-14	14-4-3-27 WPM, Man.
44	Anglo	Coates 20-13	13-20-4-27 WPM, Man.
45	Anglo et al.	McKee 15-1	1-15-3-25 WPM, Man.

Elev.	Source of Data	Waskada	Melita	Reston	Amaranth	Miss.	Dev.
	Brownell,Stott	-	-	-	92	-	179
791		-	-	-	-	-	260
850	Stott	-	-	710	-	-	660
860	Stott	-	260	360?	-	-	370
1270	Stott	-	755	1090	1210	-	1400
1494	Stott	2320	2510	2890	3040	3300	
1611	Stott	1800	1920	2365	2395	2530	
1627	Stott	1612	1775	2175	2200	2282	
1693	Stott	1680	1750	2222	2272	2370	
1783	Stott	1835	1985	2380	2430	2508	
1791	Stott	-	1298	1570	1625	-	1780
1597	Stott	-	-	-	-	1368	
1821	Stott	-	1470	-	-	-	1525
1786	Stott, Kerr	-	1435	1568	1612	-	1767
1420	Stott	-	1685	?	?	-	2910
1364	Stott	-	986	1325	-	1340	
1280	Stott	-	916	1305	1356	-	1600
1140	Stott	-	465	600	640	-	895
1369	Stott	-	-	-	-	-	665
1260	Stott	-	770	1115	1158	-	1386
1678	Stott	2245	2328	2785	2853	3096	
1534	Stott	2145	2260	2650	2790	3022	
1160	Stott	-	730	1070	1120	-	1350
1204	Stott	-	660	970	1040	-	1242
1562	Stott	-	1325	1600	1642	1798	
1339	Stott	-	410	470	550	-	700
1433	Stott	-	685	755	790	-	872
2236	Stott	-	2500	2862	2910	3200	
1483	Stott	1810	1870	2255	2370	2940	
1581	Stott	-	980	1110	-	-	1192
1612	Stott	2000	?	2475	2535	2692	
1546	Stott	-	755	794	-	-	890
1421	Stott	1496	1540	1940	2000	-	2206
1480	Stott	1750?	1900	2305	2370	2632	
1453	Stott	-	1670	1935	1960	2070	
1482	Stott	1575	1710	2090	2150	2393	
1547	Stott	-	1405	1525	-	1570	
1682	Stott	-	1183	1470	1542	-	1729
1497	Stott	2170	2350	2747	2902	3128	
1604	Stott	1543	1650	1980	2050	2115	
2183	Stott	-	2605	2982	2094	3298	
1609	Stott	-	1795	2145	2230	2384	
1881	Stott	-	1310	1435	1448	--	1463
1486	Stott	2055	2270	2692	2780	3043	
1505	Stott	1995	2137	2550	2700	2920	
1584	Stott	1922	2040	2438	2550	2795	

No.	Company	Well Name	Location
46	Cal-Stan	Whitewater 12-16	12-16-3-21 WPM, Man.
47	Nat. Bulk C.	Carriers Prov. 13-10	13-10-9-11 WPM, Man.
48	Anglo Am.	Birdtail 4-30	4-30-18-26 WPM, Man.
48?	Sohio	Barbour #1	1-4-26-2 W2, Sask.
49	B. A. Husky	Plainview #1	2-4-25-7 W2, Sask.
50	Sohio	Melville	11-14-22-6 W2, Sask.
51	Sohio	Churchbridge	6-8-22-32 WPM, Sask.
52	Tidewater	Cotham Crown #1	1-2-19-4 W2, Sask.
53	Tidewater	Hillsden Crown #1	5-30-15-5 W2, Sask.
54	Imperial	Wapella	16-33-14-1 W2, Sask.
55	B.A. Husky	Bemersyde #1	3-11.13-8 W2, Sask.
56	Tidewater	Bender Crown #1	13-11-12-5 W2, Sask.
57	Tidewater	Forget Crown #1	2-11-9-7 W2, Sask.
58	Tidewater	Arcola Crown #1	1-22-8-4 W2, Sask.
59	Socony	Redvers #1	13-36-7-32 WPM, Sask.
60	Sohio et al.	Carievale #1	16-4-3-32 WPM, Sask.
61	Cal-Stan	Frobisher	5-21-2-4 W2, Sask.
62	Spartan	Baukol Noonan #1	11-T162N-R95W, N. D.
63	Am. Petr.	H. O. Bakken #1	12-T157-R95W, N. D.
64	Pride	J. H. Kline #1	16-T157N-R85W, N. D.
65	California	B. Thompson #1	31-T160N-R81W, N. D.
66	Zach Brooks	E. Berentson #1	21-T163N-R80W, N. D.
67	Lion Oil	Magnuson #1	2-T163N-R77W, N. D.
68	Hunt Oil	Shoemaker #1	3-T157N-R78W, N. D.
69	Lion Oil	Huss #1	23-T163N-R75W, N. D.
70	Phillips Pet.	Olivia Saude	19-T158N-74W, N. D.
71	Lion Oil	Sibelius #1	23-T161N-R73W, N. D.
72	Ajax Oil	Bell #1	28-T158N-R75W, N. D.
73	Evans Prd.	A. L. Johnson #1	23-T160N-R70W, N. D.
74	Union Oil	A. & H. Saari #1	35-T161N-R68W, N. D.
75	Wakefield	E. L. Hild #1	31-T158N-R66W, N. D.
76	F. H. Rhodes	R. R. Gibbons #1	17-T157N-R65W, N. D.
77	F. H. Rhodes	Murphy #1	18-T163N-R65W, N. D.
78	Union Oil	Restad #1	26-T162N-R64W, N. D.
79	Union Oil	C. Skjervheim #1	28-T159N-R63W, N. D.
80	Turner Oil	L. G. Garp #1	7-T163N-R55W, N. D.

Elev.	Source of Data	Waskada	Melita	Reston	Amaranth	Miss.	Dev.
1664	Stott	1885	1910	2234	2312	2510	
1187	Stott	-	534	815	890	-	1070
1799	Stott	-	1440	1670	1720	-	1790
1725	Sask. Sched.	-	-	-	-	1410	
1945	CCSS[1], Stott	-	-	-	-	1870	
1796	CCSS, Stott	-	1614	-	-	1790	
1741	CCSS, Stott	-	-	-	-	1422	
1847	CCSS, Stott	-	1992	-	-	2072	
2151	CCSS, Stott	-	2610	2748	2893	3112	
1973	CCSS, Stott	-	2298	2430?	2533	2700	
2215	CCSS, Stott	-	2997	3305	3405	3680	
2498	CCSS, Stott	-	3198	3480?	3545	3906	
2002	CCSS, Stott	-	3090	3540	3652	3853	
2043	CCSS, Stott	-	3103	3540	3595	3893	
1950	CCSS, Stott	2595	2693	3020	3155	3413	
1617	CCSS, Stott	2960?	3216	3425	3525	3760	
1875	CCSS, Stott	3733	3850	4355	4445	4820	
2031	NDGS[2]	4650[3]	?	5403	?	6020	
2458	NDGS	5230	?	5960	?	6750	
1679	NDGS, Stott	3767	?	4430	4555	4945	
1526	NDGS, Stott	2860	?	3325	3470	3860	
1495	NDGS, Stott	2400	?	2950	3040	3337	
1659	NDGS, Stott	2235	?	2733	2830	3062	
1480	NDGS, Stott	2587	?	3067	3180	3460	
2205	NDGS, Stott	2764	?	3075	3220	3416	
1488	NDGS	2210	?	2560	?	2936	
1627	NDGS, Stott	2043	?	2430	2570	2653	
1510	NDGS, Stott	2058	?	2412	2500	2612	
1643	NDGS, Stott	1961	?	2296	2400	2576	
1717	NDGS, Stott	-	1883	2153	2265	-	2486
1465	NDGS	-	1630	1861		2030	
1493	NDGS, Stott	-	1580	1795	1835		1952
1597	NDGS	-	1445	1702	-	-	1775
1630	NDGS	-	1483	-	-	-	1690
1544	NDGS, Stott	1365	?	1410	1425	-	1475
?	NDGS	-	-	-	-	-	Sil.502?

[1]Central Canadian Stratigraphic Services, Ltd.

[2]North Dakota Geological Survey

[3]The Morrison formation has been included in the Swift formation by the writer.

APPENDIX II

DESCRIPTIONS OF

SELECTED LITHOLOGIC SECTIONS

DESCRIPTIONS OF SELECTED LITHOLOGIC SECTIONS

Well No. 3. Hart Green Wakely #1
1-28-4-4 WPM

Depth in feet	Lithology
0- 260	Glacial drift, unconsolidated.
	Melita
260- 370	Shale, varicoloured, light reddish-brown, greenish-grey. Sandstone, white, fine-grained, calcareous. Chara and ostracods.
	Paleozoic
370- 410	Much greyish-white chert. Dolomite, buff, siliceous. Some white gypsum.

Well No. 5. Souris Valley Gordon White #1
5-15-1-28 WPM

	Cretaceous
2240-2320	Shale, dark grey, silty. Sandstone, very fine-grained, white to light grey. Trace of pyrite. Subrounded to angular quartz grains.
	Waskada
2320-2510	Shale, greenish grey, slightly calcareous, some light grey to dark grey.
	Melita
2510-2570	Sandstone, light yellowish-brown, very fine-grained, calcareous. Shale, calcareous, light green to grey.
-2600	Limestone, light grey to mottled, dense. Shale, light grey, slightly calcareous.
-2730	Shale, green to mottled brownish-green, with some greyish-red. Traces of light buff dense limestone and sandstone.
-2800	Shale, light green and red. Sandstone with argillaceous patches, light grey, very fine-grained.
-2890	Shale, varicoloured. Sandstone, calcareous, light grey. Some loose quartz grains, subrounded.
	Reston
2890-3040	Limestone, finely crystalline, creamy white. Some green, red, and dark grey shale. Traces of anhydrite.

Depth in feet	Lithology
	Amaranth
3040-3190	Anhydrite, white, crystalline, with buff dolomite. Some varicoloured and dark grey shales.
-3300	Shale, light to medium grey, red. Siltstone, orange-red.
	Mississippian
3300-	Dolomite, buff, dense.

Well No. 6. California Standard Ewart Province 4-14.
4-14-10-28 WPM

	Cretaceous
1770-1800	Shale, medium grey, slightly calcareous, micaceous. Some glauconite.
	Waskada
1800-1920	Sandstone, fine-grained, calcareous, white, pyritic. Shale, medium grey, greenish-grey, bentonitic. Trace of orange and brown shales.
	Melita
1920-2162	Shale, greenish-grey, calcareous. Siltstone, calcareous. Traces of fossiliferous limestone and varicoloured shales.
-2355	Shales, greenish-grey, brown, mottled green and rusty red, yellowish-brown. Some chalky white limestone. Belemnite fragment, gastropod.
-2365	Shale, medium to dark grey, with some greenish-grey, calcareous. Abundant fossil fragments.
	Reston
2365-2385	Limestone, sandy, oolitic, buff.
-2395	Limestone, buff, slightly argillaceous to sandy. Some chert pebbles.
	Amaranth
2395-2510	Anhydrite, white. Shale, brown. Dolomite, dense, buff.
-2535	Shale, dark grey to black, and rusty red.
	Mississippian
2535-2550	Dolomite, buff with pink streaks, slightly sandy.

Well No. 8. California Standard West Daly Province 8-29.

Depth in feet	Lithology
	Cretaceous
1600-1690	Shale, medium to dark grey, fissile. Trace of glauconite.
	Waskada
1690-1750	Shale, grey to greyish-green, bentonitic. Silt, light grey, calcareous.
	Melita
1750-1770	Limestone, sandy, oolitic. Shale, medium grey to greenish-grey.
-2090	Shale, greenish-grey, light to medium grey, slightly calcareous. Sandstone, very fine-grained, calcareous. Traces of mottled, fossiliferous limestone.
-2222	Shale, light grey, reddish brown, greenish-grey, brown, yellowish-brown. Sandstone, fine-grained, calcareous.
	Reston
2222-2237	Limestone, sandy, oolitic. Shale, medium grey.
-2242	Limestone, sandy, light grey, with grains of rounded chert.
-2247	Shale, light to medium grey, extremely calcareous, fossiliferous.
-2266	Limestone, sandy, with thin bands of green and dark grey shale. Dense blue chert fragments occur near base.
	Amaranth
2266-2268	Erosional contact. Dolomite, brown, dense, with chert concretions.
-2273	Dolomite breccia, buff, with chert concretions.
-2277	Anhydrite, bluish-white, dense to finely crystalline with thin laminae of buff dolomite.
-2360	Anhydrite, bluish-white, dense, with buff dolomite. Shales, reddish brown, grey.
	Mississippian
2360-2380	Dolomite, yellowish-brown, finely crystalline. Chert, pinkish-white. Trace of oil staining.

Well No. 10.	Imperial Birtle #1 1-27-17-26 WPM
Depth in feet	Lithology
	Cretaceous
1220-1298	Shale, medium to dark grey, micaceous. Trace of brown siltstone.
	Melita
1298-1380	Shale, light greenish - to brownish grey, slightly calcareous. Numerous shell fragments.
-1430	Sandstone, very fine-grained, calcareous, white. Some pyrite and shale as above.
-1525	Shale, brownish-grey, yellowish-brown, soft and crumbly, slightly calcareous. Sandstone, white to greyish-green, fine-grained, calcareous.
-1570	Shale, brick red, yellowish-brown, greyish-green, and yellow.
	Reston
1570-1600	Limestone, oolitic, sandy. Some red and yellow shale.
-1625	Limestone, light buff, dense, argillaceous.
	Amaranth
1625-1655	Dolomite, creamy buff, dense. Abundant blue-white chert at top.
-1730	Anhydrite, dense, white, and dolomite, light buff, dense, argillaceous. Varicoloured shales.
-1780	Siltstone, brownish-red. Some reddish-brown shale. Traces of chert and anhydrite.
	Devonian
1780-	Dolomite, dense, greyish, with veinlets of anhydrite.

Well No. 13. Jean Cleland #3
4-22-20-25 WPM

Lithology summarized from unpublished core log by Kerr of Manitoba Mines Branch.

	Melita
1435-1568	Shale, red, calcareous and light green. Siltstone, grey with carbonaceous material. Limestone, light grey.
	Reston
1568-1612	Limestone, light grey, somewhat argillaceous, dolomitic toward the base, with patches of bluish-grey chert. Some shaly bands.

Depth in feet	Lithology
	Amaranth
1612-1675	Anhydrite with stringers and patches of dolomite.
-1688	Brecciated anhydrite and shale. Siltstone, mottled shades of red and green, with minor amounts of anhydrite.
-1765	Siltstone, shades of red and green, with associated anhydrite. Breccia zone, one and one-half feet thick, at base.
	Devonian
1767-	Dolomite.

Well No. 15. California Standard Wawanesa 3-1.
3-1-8-18 WPM

	Melita
986-1180	Sandstone, fine-grained, pyritic, calcareous. Shale, greyish-green, light brown, calcareous. Some mottled limestone.
-1325	Varicoloured shales. Trace of ostracods. Sandstone, light grey, calcareous.
	Reston
1325-1340	Limestone, sandy, oolitic to dense.
	Mississippian
1340-	Dolomite, pale yellowish-brown. Abundant white chert.

Well No. 16. Brandon Coutts #2
14-16-10-19 WPM

	Cretaceous
846-916	Shale, medium grey with thin partings of silty sandstone. Sandstone, fine-grained, extremely pyritic, calcareous.
	Melita
916-1146	Shale, medium to dark grey, and greenish-grey, slightly calcareous. Trace of fine sandstone, calcareous, greenish-white. Shell fragments.
-1305	Shale, medium grey, greyish-green, reddish-brown. Some limestone, dense, light brownish-grey. Sandstone, fine-grained, calcareous.
	Reston
1305-1356	Limestone, buff-white, dense to crystalline. Grey shale.

Depth in feet	Lithology
	Amaranth
1356-1476	Anhydrite, white, dense. Dolomite, buff, dense. Varicoloured shales.
-1600	Shale, brick red, greyish-green, brownish-grey. Siltstone, brick red. Some coarse, rounded quartz grains at base.
	Devonian
1600-1630	Limestone, dolomitic, light buff with reddish streaks, dense.

Well No. 17 Langford #1
5-29-14-14 WPM

	Cretaceous
400- 465	Poor samples. Abundant loose quartz grains, medium-grained, subangular to subrounded. Shale, medium grey to greenish-grey.
	Melita
465- 600	Shale, medium grey, greenish-grey. Sandstone, fine-grained, calcareous.
	Reston
600- 640	Limestone, slightly dolomitic, light buff, dense to finely crystalline. Shale, dark grey.
	Amaranth
640- 770	Gypsum and anhydrite, white. Dolomite, light buff. Variegated shales.
- 895	Shales, dark grey, reddish brown, dolomitic. Sandstone, brick red, fine-grained.
	Devonian
895-	Dolomite, buff to pinkish buff, finely crystalline.

Well No. 22. California Standard Spruce Woods Structure Test #3.
10-4-8-15 WPM

	Cretaceous
695- 730	Shale, dark grey. Some loose quartz grains. Pyrite.
	Melita
730- 740	Sandstone, fine-grained, white, calcareous, not well cemented.
- 755	No sample.

Depth in feet	Lithology
755- 800	Shale, pale green, calcareous, soft.
-1070	Shales, red, green, brown, calcareous, silty and sandy in some zones.
	Reston
1070-1120	Limestone, white to light buff, dense. Some dark grey shale.
	Amaranth
1120-1250	Dolomite, buff to olive-grey, dense. Anhydrite and gypsum, white.
-1350	Shale, red, silty. Siltstone, brick red. Traces of gypsum.
	Devonian
1350-	Limestone, dolomitic, buff.

Well No. 26. British American Grandview #1
16-30-24-23 WPM

	Cretaceous
630- 685	Shale, medium to dark grey, and sandstone, grey, shaly, fine-grained, pyritic.
	Melita
685- 755	Sandstone, white, fine-grained, calcareous. Shale, medium grey, silty. Traces of limestone.
	Reston
755- 790	Limestone, sandy, buff to white.
	Amaranth
790- 872	Siltstone, brick red, and shale, dolomitic. Trace of gypsum.
	Devonian
872-	Dolomite, vuggy to dense, buff.

Well No. 28. California Standard Reston Beattie 7-27
7-27-6-27 WPM

	Cretaceous
1760-1780	Shale, medium to dark grey. Silt, light grey to brownish-grey. Trace of fine-grained sandstone.

Depth in feet	Lithology
1780-1824	Shale and silt, as above. Coarse, loose quartz grains, subangular to subrounded, slightly frosted. Some pyrite.
	Waskada
1824-1870	Shale, silty, calcareous, light greyish-green to greenish-brown. Sandstone, fine-grained, light grey, calcareous.
	Melita
1870-1910	Limestone, mottled, fossiliferous. Shale, medium to dark grey.
-2110	Shale, light to medium grey, greenish-grey, slightly calcareous. Sandstone, greenish-white, calcareous, fine-grained. Traces of mottled, fossiliferous limestone.
-2255	Shales, brick red, greyish-green, yellowish-brown, light grey. Trace of dense buff limestone and calcareous fine-grained sandstone.
	Reston
2255-2310	Limestone, sandy, oolitic. Traces of dark shale.
-2370	Limestone, buff-white, dense, slightly dolomitic, with traces of pink anhydrite.
	Amaranth
2370-2520	Anhydrite, bluish-white, finely crystalline, with some buff dolomite.
-2640	Sandstone, orange-red, slightly calcareous, fine-grained. Shale, red, grey and brown. Some pink anhydrite.
	Mississippian
2640-2660	Dolomite, dense, pink to buff with reddish streaks.

Well No. 32 California Standard Findlay 9-26
9-26-7-25 WPM

Depth in feet	Lithology
	Cretaceous
1420-1495	Shale, medium to dark grey, with traces of fine-grained, calcareous sandstone.
	Waskada
1495-1540	Shale, pale green, calcareous, soft. Trace of pink anhydrite.

Depth in feet	Lithology
	Melita
1540-1780	Shale, green, olive-grey, calcareous. Sandstone, fine-grained, calcareous.
-1940	Shale, reddish-brown, greyish-green, yellowish-grey. Chara and shell fragments.
	Reston
1940-2000	Limestone, buff to white, dense, some sandy. Shell fragments.
	Amaranth
2000-2142	Anhydrite, white crystalline. Some dolomite, dense, buff, and shale, brown to grey.
-2206	Shale, orange-red, some brick red, dolomitic. Much red silt.
	Mississippian
2206-2220	Limestone, dolomitic, grey streaked with red. White chert.

Well No. 33. Souris Valley Y. P. F. McInnes #1
8-20-4-25 WPM

	Cretaceous
1750-1800	Shale, dark grey to black. Sandstone, light grey.
-1815	Shale, dark grey to black. Subrounded to rounded quartz grains. Some pyritic sandstone.
	Waskada
1815-1900	Shale, light green, calcareous, bentonitic. Some white to light grey, sandstone, argillaceous, calcareous.
	Melita
1900-2020	Shale, greenish-grey. Sandstone, very fine-grained. Shell fragments. Glauconite.
-2180	Shale, medium grey to greenish-grey. Sandstone, fine-grained, calcareous. Sandy limestone. Belemnite fragments.
-2305	Shale, light to medium grey, greenish-grey, reddish-brown. Sandstone, fine-grained white to brownish-red. Shell fragments are numerous.
	Reston
2305-2370	Limestone, light buff, dense. Some dark grey shale. Dense pink chert at base.

Depth in feet	Lithology
	Amaranth
2370-2515	Anhydrite, bluish-white, crystalline. Shale, brown, reddish to grey.
-2632	Shale, dark grey, green, red. Sandstone, fine-grained, reddish-brown. Traces of anhydrite.
	Mississippian
2632-	Dolomite, light brown, dense.

Well No. 34. Royalite Triad et al East Hartney #1
7-27-5-24 WPM

	Cretaceous
1550-1670	Shale, medium to dark grey. Much silty shale. Loose quartz grains, siderite pebbles.
	Melita
1670-1750	Shale, pale greyish-green. Traces of mottled limestone. Some silty, greenish-white sandstone.
-1890	Shale, brownish-grey, soft, somewhat crumbly, slightly calcareous. Trace of white, calcareous sandstone and shell fragments.
	Reston
1890-1970	Limestone, light buff, dense to sandy. Shale, medium grey.
	Amaranth
1970-2010	Anhydrite, finely crystalline, white. Reddish shale. Buff dolomite.
-2070	Shale, dolomitic, brick red, becomes silty towards the base. Siltstone, brick red. Trace of pink anhydrite.
	Mississippian
2070-2090	Limestone, dolomitic, finely crystalline, buff with some deep red to purplish streaks. Some appears fragmental and has associated gypsum.

Well No. 37. Baysel Bruxelles 1-27
1-27-6-11 WPM

	Cretaceous
1100-1183	Shale, medium grey, pyritic. Some very coarse subrounded pitted quartz grains.

Depth in feet	Lithology
	Melita
1183-1340	Sandstone, white calcareous, fine-grained. Shale, brownish-grey, medium grey to greyish-green. Some limestone, buff, dense to fossiliferous.
-1470	Shale, orange red, purplish-red, greyish-green, olive green, calcareous. Ostracods.
	Reston
1470-1542	Limestone, buff white, chalky, finely porous to vuggy.
	Amaranth
1542-1598	Anhydrite, white, finely crystalline, and buff dolomite. Shale, medium grey to brown.
-1729	Siltstone, shaly, brick red. Shale, brick red, mottled. Traces of anhydrite.
	Devonian
1729-	Dolomite, limy, buff, sandy.

Well No. 43 — Anglo Skelton 4-14, 14-4-3-27 WPM

	Cretaceous
1960-1970	Shale, dark grey. Trace of pyritic sand.
-2055	Sandstone, pyritic, colourless, coarse- to fine-grained, calcareous. Quartz is subangular to subrounded. Shale, dark grey to black.
	Waskada
2055-2140	Shale, light grey to black. Some sandstone, fine-grained, reddish.
-2270	Shale, greenish-grey to medium grey. Sandstone, very fine-grained, creamy white, slightly calcareous. Traces of carbonaceous material.
	Melita
2270-2500	Shale, light greenish-grey, calcareous. Some soft silty sand. Traces of limestone, mottled, finely crystalline to sandy.
-2692	Shale, variegated, red, and green, with traces of mottled limestone and pyrite. Some very fine-grained white calcareous sandstone.
	Reston
2692-2780	Limestone, finely crystalline, white, and some dark grey shale.

Depth in feet	Lithology
	Amaranth
2780-2940	Anhydrite, white, finely crystalline, and traces of gypsum. Some dark grey to brownish shale and buff dolomite.
-3000	Shale, red, silty. Some reddish-brown fine-grained sandstone.
-3043	Shales, shades of grey to red. Fine-grained reddish sandstone and rounded quartz of medium size.
	Mississippian
3043-	Dolomite.

Well No. 44

Anglo Coates 20-13
13-20-4-27 WPM

	Cretaceous
1930-1995	Shale, medium to dark grey. Sandstone, medium to coarse grained, pyritic. Loose quartz grains, subrounded to rounded, slightly frosted and pitted.
	Waskada
1995-2137	Shale, dark grey, reddish. Sandstone, white to rusty red, fine-grained. Trace of greyish-green shale.
	Melita
2137-2170	Limestone, white, oolitic to sandy. Shale, medium to dark grey, brownish, greenish-grey.
-2230	Shale, medium to light grey, greenish-grey, slightly calcareous.
-2250	Shales, olive green, red, grey, brown. Some sandstone, quartzose, calcareous.
-2400	Shale, light to medium grey, olive green, brown. Some limestone, buff brown to mottled, fossiliferous to finely crystalline.
-2550	Shales, varicoloured. Small quantity of sandstone.
	Reston
2550-2570	Limestone, buff white, sandy to oolitic. Shale, medium to dark grey.
-2700	Limestone, light buff, dense, sandy to chalky in some zones. Some light grey shale.
	Amaranth
2700-2815	Anhydrite, white, finely crystalline. Some buff dolomite and variegated shales.

Depth in feet	Lithology
2815-2920	Shale, orange-red, dolomitic. Sandstone, fine-grained, orange-red.
	Mississippian
2920-2950	Dolomite, light buff, dense, massive.

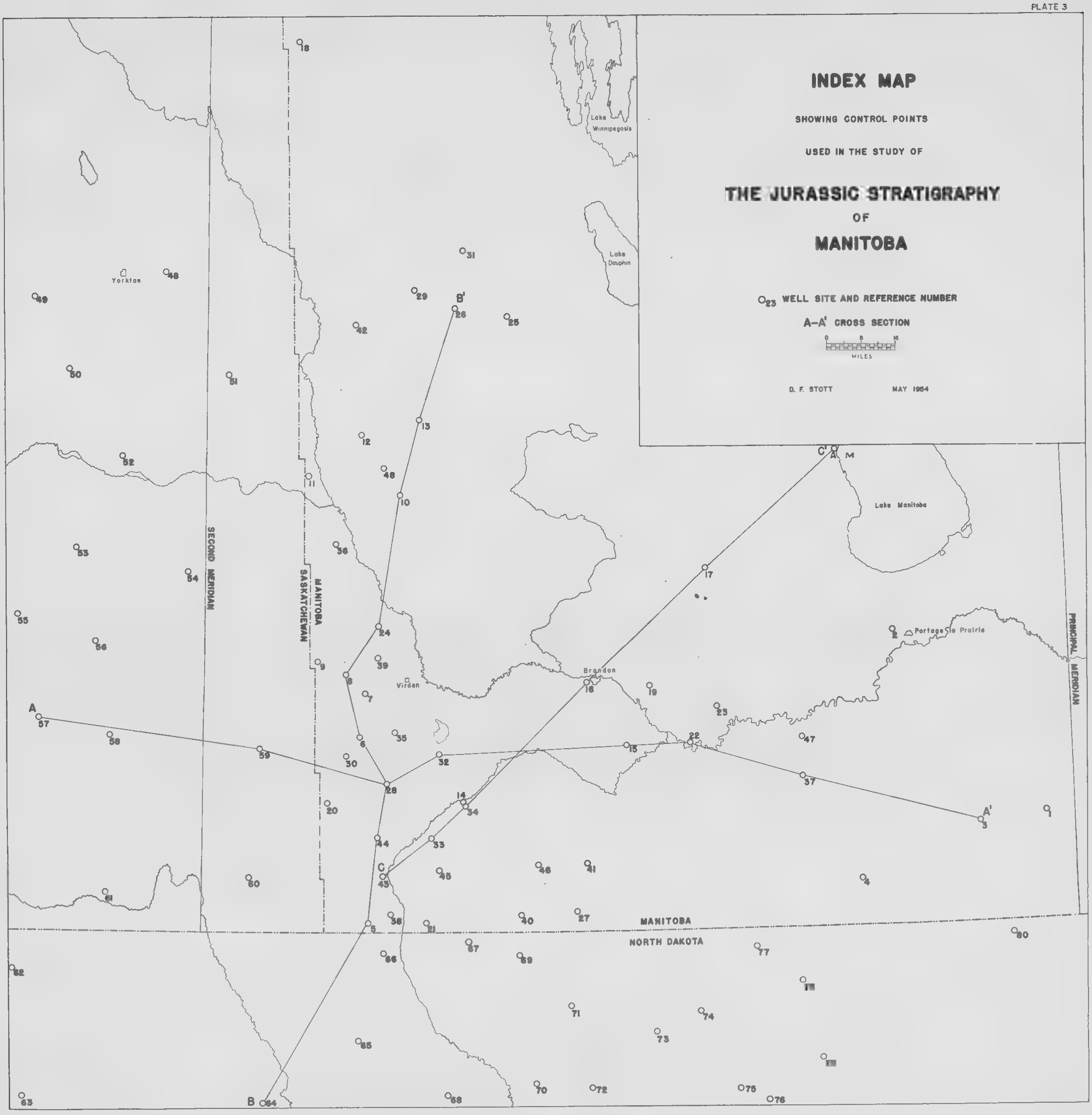
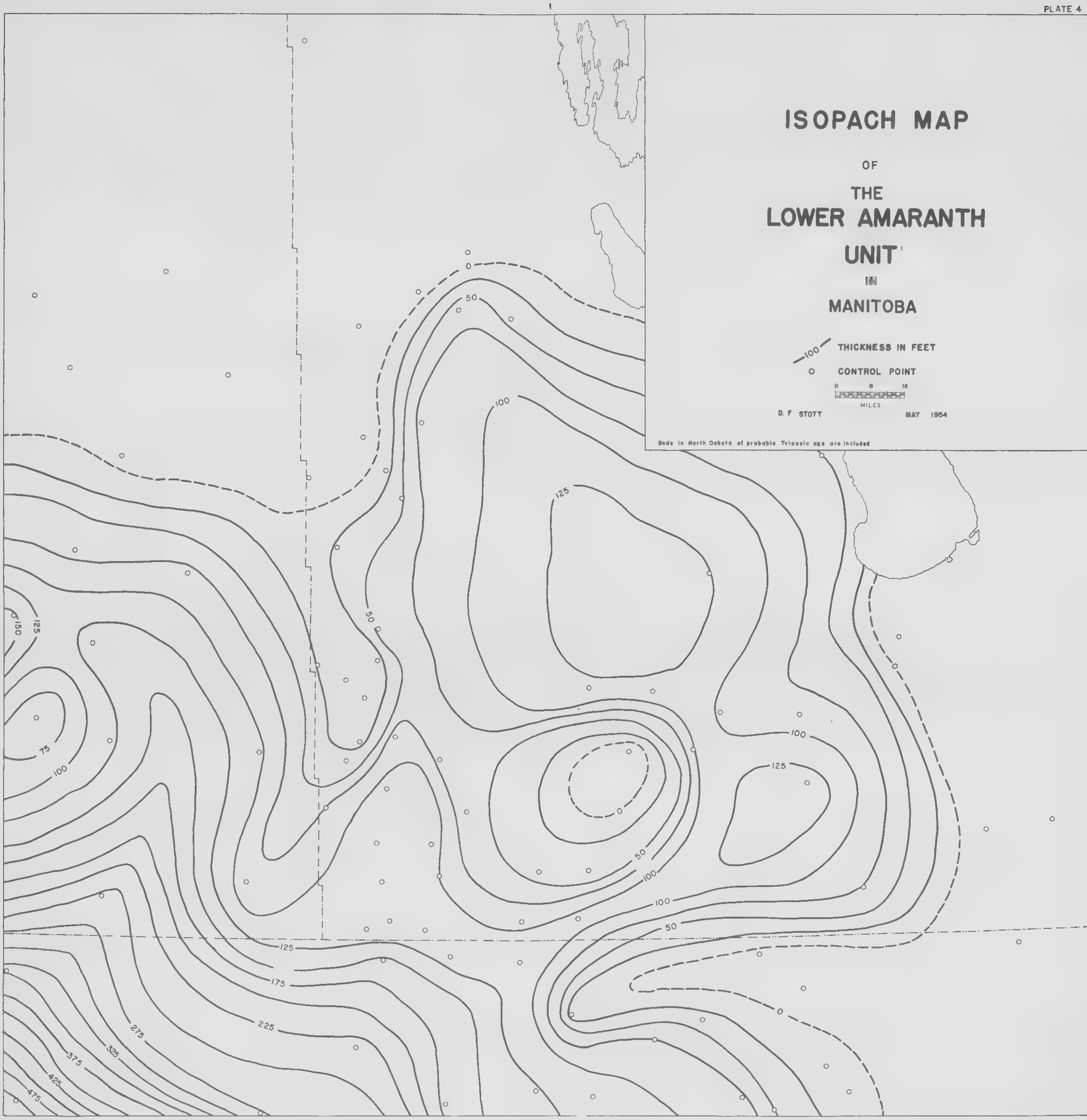

INDEX MAP
SHOWING CONTROL POINTS
USED IN THE STUDY OF
THE JURASSIC STRATIGRAPHY
OF
MANITOBA
WELL SITE AND REFERENCE NUMBER
A–A' CROSS SECTION
MILES
D. F. STOTT
MAY 1954
Lake Winnipegosis
Lake Dauphin
Lake Manitoba
Yorkton
Virden
Brandon
Portage la Prairie
SECOND MERIDIAN
MANITOBA
SASKATCHEWAN
PRINCIPAL MERIDIAN
MANITOBA
NORTH DAKOTA

PLATE 4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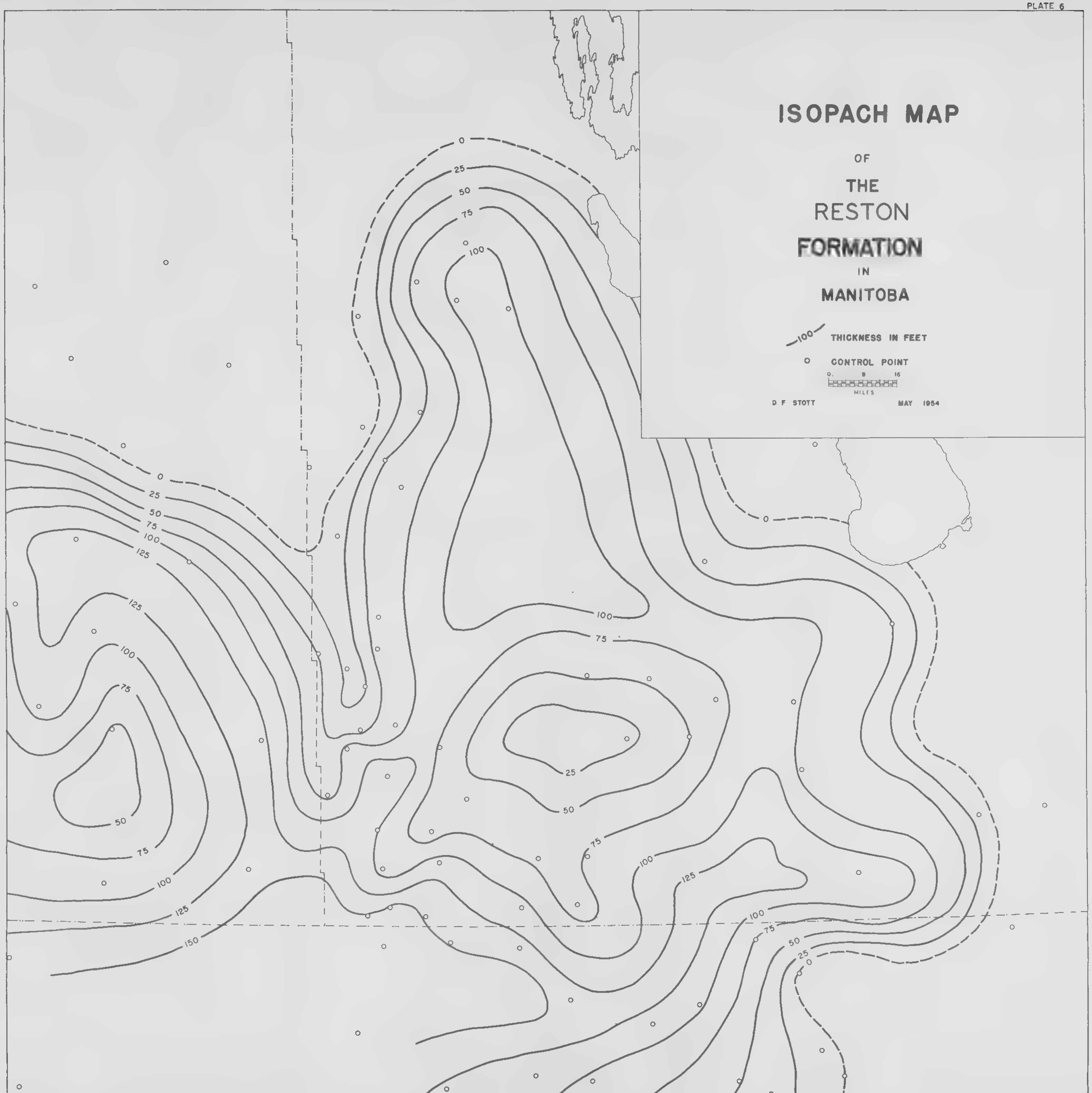
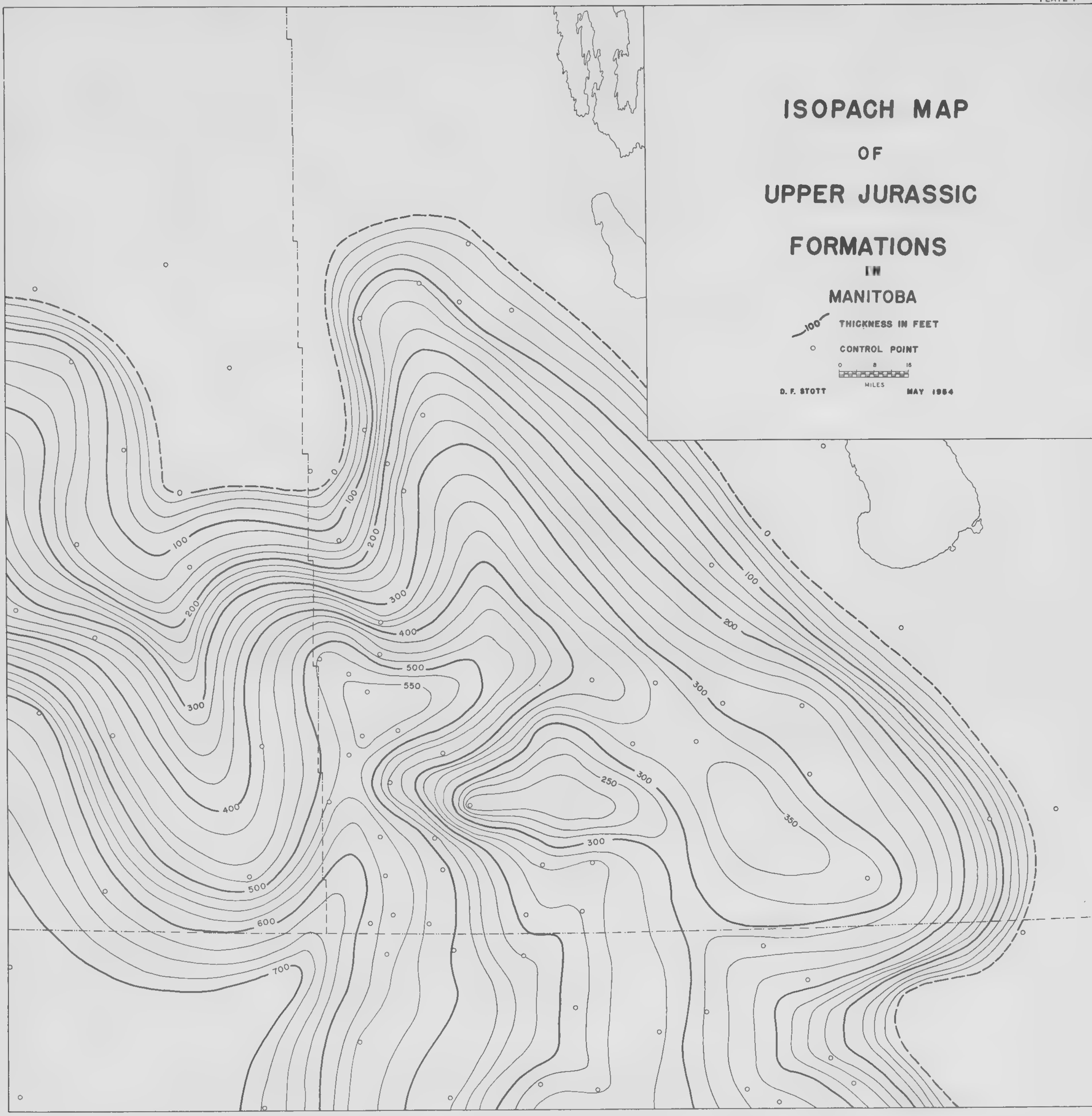
OF
THE
LOWER AMARANTH
UNIT
IN
MANITOBA
100 THICKNESS IN FEET
O CONTROL POINT
0 8 16
MILES
D. F STOTT
MAY 1964
Beds in North Dakota of probable Triassic age are included
0
50
100
125
150
75
175
225
275
325
375
425
475

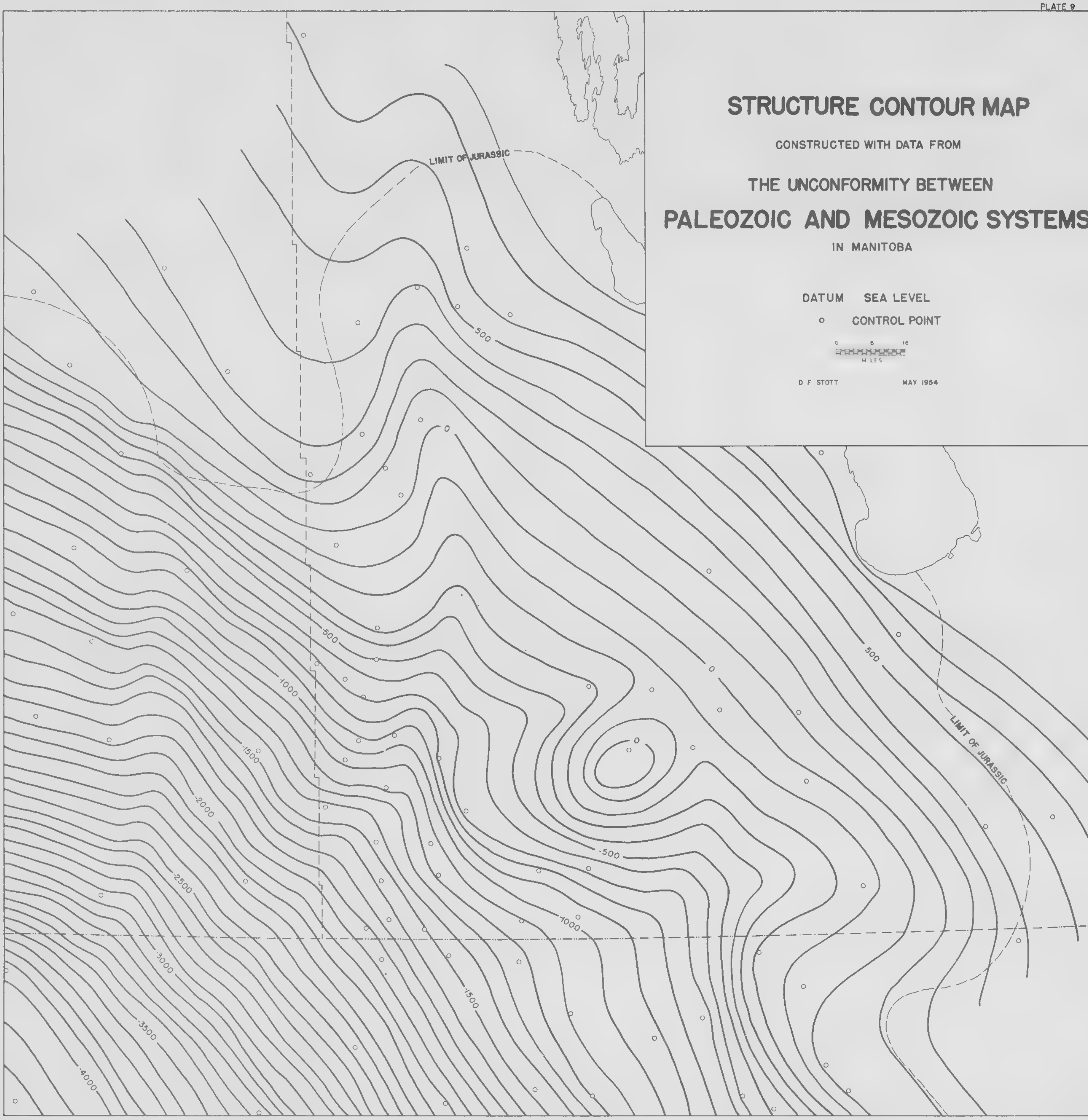

ISOPACH MAP
OF
THE
UPPER AMARANTH
UNIT
IN
MANITOBA
100 THICKNESS IN FEET
CONTROL POINT
0 8 16
MILES
D. F. STOTT
MAY 1954
0
25
50
75
100
125
150
175


ISOPACH MAP
OF
THE
RESTON
FORMATION
IN
MANITOBA
100
THICKNESS IN FEET
CONTROL POINT
0 8 16
MILES
D F STOTT
MAY 1954
0
25
50
75
100
125
150


ISOPACH MAP
OF
UPPER JURASSIC
FORMATIONS
IN
MANITOBA
100 THICKNESS IN FEET
CONTROL POINT
0 8 16
MILES
D. F. STOTT
MAY 1954
0
100
200
300
400
500
550
250
350
600
700


ISOPACH MAP
OF
THE
JURASSIC
SYSTEM
IN
MANITOBA
THICKNESS IN FEET
CONTROL POINT
MILES
D. F. STOTT
MAY 1954

PLATE 9



STRUCTURE CONTOUR MAP
CONSTRUCTED WITH DATA FROM
THE UNCONFORMITY BETWEEN
PALEOZOIC AND MESOZOIC SYSTEMS
IN MANITOBA
DATUM SEA LEVEL
CONTROL POINT
MILES
D F STOTT
MAY 1954
LIMIT OF JURASSIC
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000


STRUCTURE CONTOUR MAP
CONSTRUCTED WITH DATA FROM
THE TOP OF THE
JURASSIC SYSTEM
IN MANITOBA
DATUM SEA LEVEL
CONTROL POINT
0 8 16
MILES
D. F. STOTT
MAY 1954
LIMIT OF JURASSIC
LIMIT OF JURASSIC
500
0
-500
-500
-1000
-1500
-2000
-2500

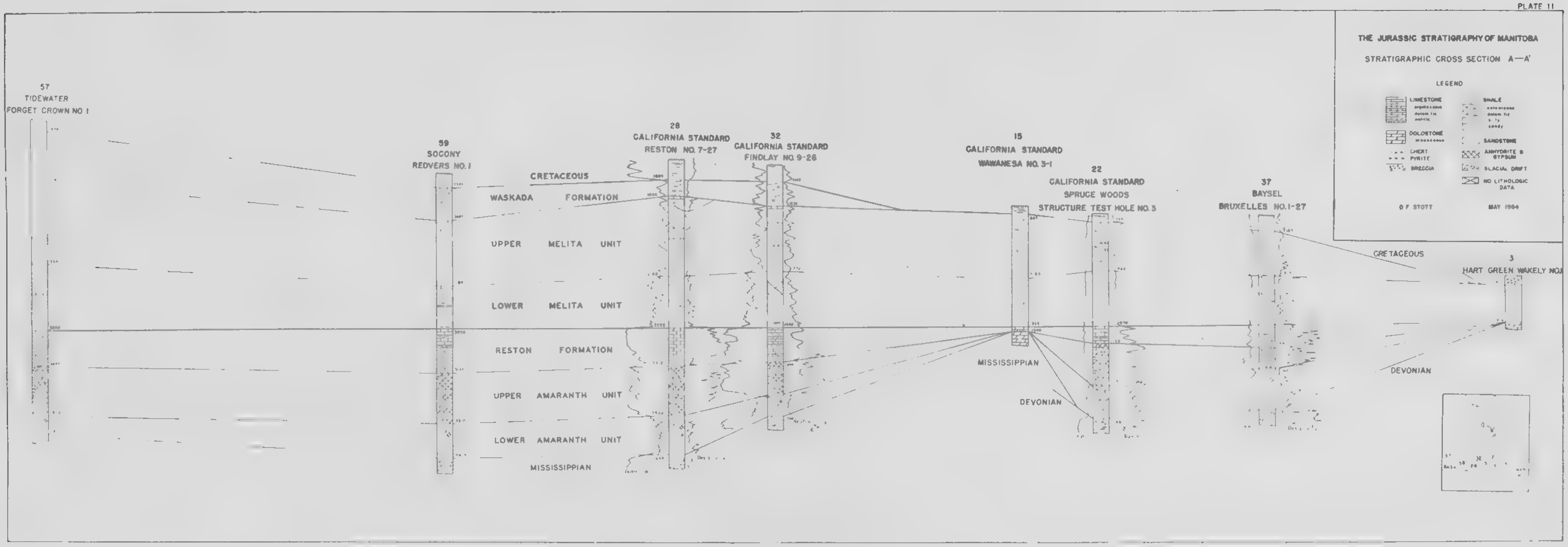

THE JURASSIC STRATIGRAPHY OF MANITOBA
STRATIGRAPHIC CROSS SECTION A—A'
LEGEND
LIMESTONE
DOLOSTONE
CHERT
PYRITE
BRECCIA
SHALE
SANDSTONE
ANHYDRITE & GYPSUM
GLACIAL DRIFT
NO LITHOLOGIC DATA
D F STOTT
MAY 1964
57
TIDEWATER
FORGET CROWN NO. 1
59
SOCONY
REDVERS NO. 1
28
CALIFORNIA STANDARD
RESTON NO. 7-27
32
CALIFORNIA STANDARD
FINDLAY NO. 9-26
15
CALIFORNIA STANDARD
WAWANESA NO. 3-1
22
CALIFORNIA STANDARD
SPRUCE WOODS
STRUCTURE TEST HOLE NO. 3
37
BAYSEL
BRUXELLES NO. 1-27
3
HART GREEN WAKELY NO.1
CRETACEOUS
WASKADA FORMATION
UPPER MELITA UNIT
LOWER MELITA UNIT
RESTON FORMATION
UPPER AMARANTH UNIT
LOWER AMARANTH UNIT
MISSISSIPPIAN
MISSISSIPPIAN
DEVONIAN
CRETACEOUS
DEVONIAN

PLATE 12.

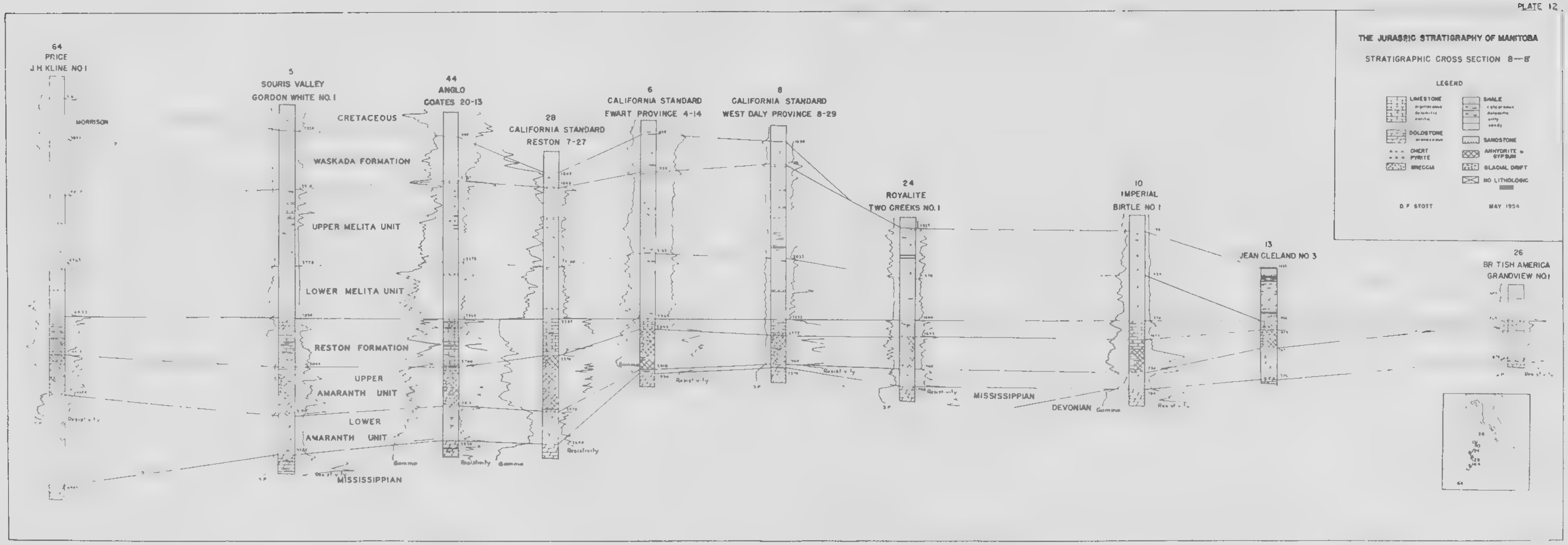
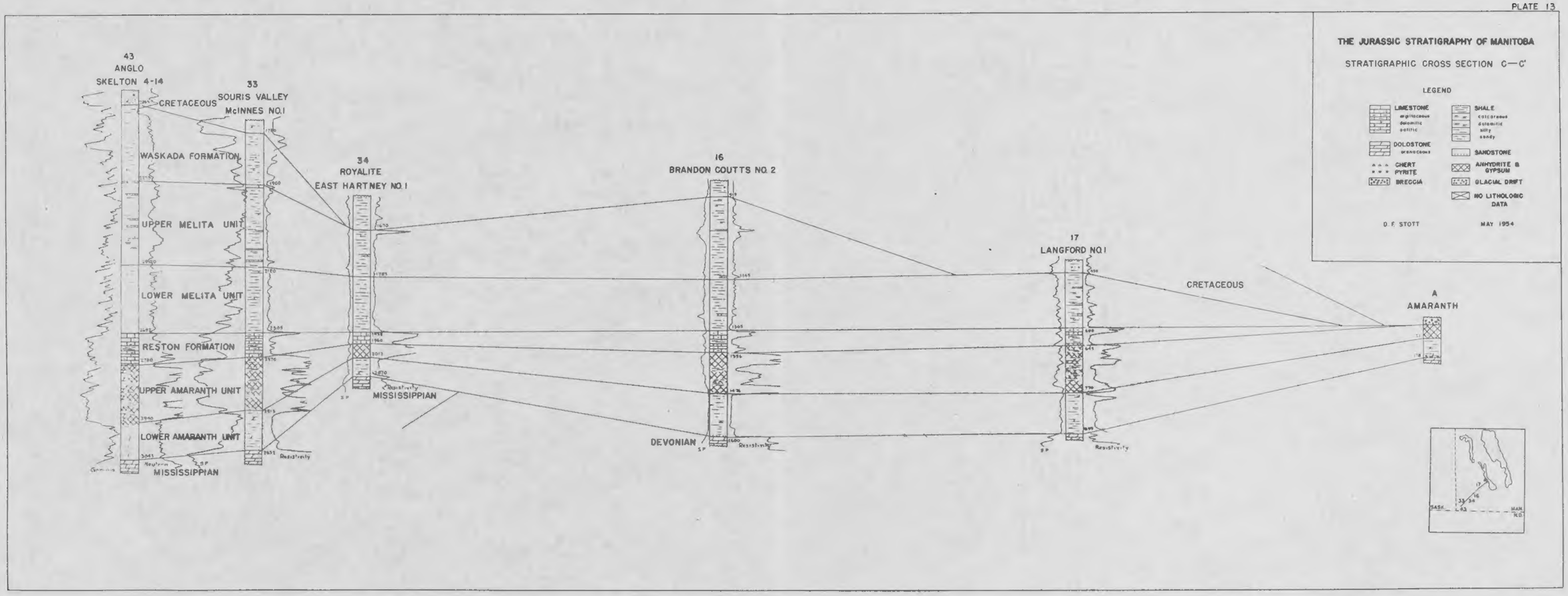

THE JURASSIC STRATIGRAPHY OF MANITOBA
STRATIGRAPHIC CROSS SECTION B—B'
LEGEND
LIMESTONE
DOLOSTONE
CHERT
PYRITE
BRECCIA
SHALE
SANDSTONE
ANHYDRITE & GYPSUM
GLACIAL DRIFT
NO LITHOLOGIC
D.F. STOTT
MAY 1954
64
PRICE
J.H. KLINE NO.1
MORRISON
5
SOURIS VALLEY
GORDON WHITE NO.1
44
ANGLO
COATES 20-13
28
CALIFORNIA STANDARD
RESTON 7-27
6
CALIFORNIA STANDARD
EWART PROVINCE 4-14
8
CALIFORNIA STANDARD
WEST DALY PROVINCE 8-29
24
ROYALITE
TWO CREEKS NO.1
10
IMPERIAL
BIRTLE NO.1
13
JEAN CLELAND NO.3
26
BRITISH AMERICA
GRANDVIEW NO.1
CRETACEOUS
WASKADA FORMATION
UPPER MELITA UNIT
LOWER MELITA UNIT
RESTON FORMATION
UPPER
AMARANTH UNIT
LOWER
AMARANTH UNIT
MISSISSIPPIAN
DEVONIAN
Gamma
Resistivity

PLATE 13


THE JURASSIC STRATIGRAPHY OF MANITOBA
STRATIGRAPHIC CROSS SECTION C—C'
LEGEND
LIMESTONE
argillaceous
dolomitic
oolitic
DOLOSTONE
arenaceous
CHERT
PYRITE
BRECCIA
SHALE
calcareous
dolomitic
silty
sandy
SANDSTONE
ANHYDRITE & GYPSUM
GLACIAL DRIFT
NO LITHOLOGIC DATA
D. F. STOTT
MAY 1954
43
ANGLO
SKELTON 4-14
33
SOURIS VALLEY
McINNES NO.1
34
ROYALITE
EAST HARTNEY NO.1
16
BRANDON COUTTS NO.2
17
LANGFORD NO.1
A
AMARANTH
CRETACEOUS
WASKADA FORMATION
UPPER MELITA UNIT
LOWER MELITA UNIT
RESTON FORMATION
UPPER AMARANTH UNIT
LOWER AMARANTH UNIT
MISSISSIPPIAN
DEVONIAN
CRETACEOUS
Resistivity
S.P.

PROVINCE OF MANITOBA

Department of Mines and Natural Resources

MINES BRANCH

MAPS AND SECTIONS

JURASSIC STRATIGRAPHY OF MANITOBA

by

Donald F. Stott

To accompany Publication 54-2